AD-A159 543 COMPARISON OF NARROO-BAND AND ONE-THIRD OCTAVE AMBIENT NOISE MEASUREMENTS(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA R M LOVELACE JUN 85 NPS-68-85-019 1/1

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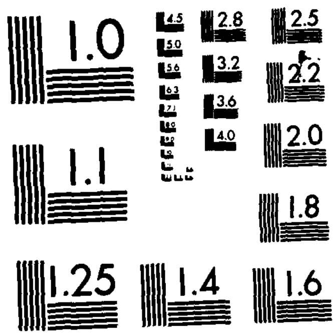

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

COMPARISON OF NARROW-BAND AND ONE-THIRD OCTAVE AMBIENT NOISE MEASUREMENTS

by

Ronald M. Lovelace

June 1985

Thesis Co-Advisors: C. R. Dunlap / R. H. Bourke

Prepared for:
Space and Naval Warfare Systems Command
(SPAWAR 6124)
Washington, DC 20363-5100

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This thesis was prepared in conjunction with research supported in part by Space and Naval Warfare Systems Command work order N0003985WRDW034.

Released as a
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NPS-68-85-019	2. GOVT ACCESSION NO. AD-A159543	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A Comparison of Narrow-Band and One-third Octave Ambient Noise Measurements.		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis June 1985
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ronald M. Lovelace in conjunction with C.R. Dunlap and R.H. Bourke		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, CA 93943-5100		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS PE 62759N N0003985WRDW034
11. CONTROLLING OFFICE NAME AND ADDRESS Space and Naval Warfare Systems Command (SPAWAR 6124) Washington, DC 20363-5100		12. REPORT DATE June 1985
		13. NUMBER OF PAGES (76)
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ambient Noise	Oceanographic Measurements	WOTAN
ARGOS	ASNI	
Drifting Buoys	NADS	
Marine Winds	Air-Sea Interaction	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In preparation for the eventual testing of a drifting environmental acoustic buoy, the ambient noise in a area off the Monterey, California coast was measured using two analysis methods. Narrow band processing (9 Hz) was compared to 1/3 octave band processing for frequencies up to 2500 Hz. Noise

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Comparison of Narrow Band and One Third Octave Band Ambient Noise Measurements

by

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Lieutenant United States Navy
B.S., United States Naval Academy, 1978

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ENGINEERING ACOUSTICS

from the

NAVAL POSTGRADUATE SCHOOL
June 1985

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ABSTRACT

In preparation for the eventual testing of a drifting environmental acoustic buoy, the ambient noise in an area off the Monterey, California coast was measured using two analysis methods. Narrow band processing (9 Hz) was compared to 1/3 octave band processing for frequencies up to 2500 Hz. Noise generation due to shipping and local wind was examined for the contribution of each to the noise spectrum. Noise spectrum levels measured using either approach agreed within 2 dB, usually within 1 dB. Local and distant shipping varied on a daily basis and appeared to coincide with port activity. The mean variability at 50 Hz was 5 dB for hourly records influenced by individual ships. Distant shipping at 50 Hz showed a 2-3 dB variation. Also, this study shows that mean ambient noise curves may be used to estimate wind speed using the ambient noise at 1700 Hz, provided there are no local ships within 16 km. Ships at greater range appear to contribute little to the wind-dependent spectrum at 1700 Hz.

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I. INTRODUCTION

A. THE NADS BUOY

Drifting buoys are becoming increasingly useful tools in measuring atmospheric, oceanographic and acoustic parameters of the ocean environment. With present satellite technology it is possible to collect in-situ data from the air-ocean environment and relay it to monitoring stations. An experimental drifting buoy system, the Naval Postgraduate School (NPS) Ambient Noise Drifting Buoy System (NADS), is presently under construction at the Polar Research Laboratory (PRL) in Santa Barbara, CA. The NADS buoy is designed to measure ambient noise, subsurface temperature, wind speed and other meteorological parameters. The data, including buoy position, will be telemetered via the ARGOS system utilizing the NOAA series satellites. Buoy position will be determined by the doppler shift of data at the satellite (PRL, 1984). The NADS is designed to operate for 1 yr based upon the estimated power consumption and its useful battery life.

Parameters to be sensed by the drifting acoustic buoy include the following:

1. low frequency ambient noise in eleven, 1/3 octave bands measured by hydrophones at 30 m and 305 m depth,
2. subsurface temperature at ten depths to 305 m,
3. hydrostatic pressure at two locations to define the depth of the thermistor string at two points,
4. near sea surface temperature at 1 m below the sea surface,

Wind speed and sea state were estimated by the ship's master. Shipping traffic was monitored by the ship's radar. No BT or sound speed data were measured due to a malfunction of the processing system aboard the ACANIA. The acoustic projector was actuated at 35 km from shore and again between Stations 2 and 3 while the ACANIA was dead in the water.

2. December 12, 1984

The weather changed dramatically from the previous day with the passage of a storm. Winds of 20-26 m/s and wave heights of 4.8-5.4 m were reported. The ACANIA was not able to reach Station 1 due to the extreme sea conditions. Prior to returning to port, a deep and a shallow SSQ-41B were deployed at position 36°39'N, 122°03'W in 550 m of water. Ambient noise data were recorded to determine wind and storm noise effects. A temperature and sound speed probe were launched at the buoy location. No shipping was sighted prior to returning to port.

3. February 26, 1985

A deep and a shallow SSQ-57 buoy were deployed at Station 1. Wind speed was recorded hourly using the 14.5 m anemometer on board the ACANIA and the hand-held model at 10 m. Local shipping and estimates of wave height were recorded. The ACANIA towed the acoustic projector and remained within 10 km of the buoys. Two hours of noise data were lost due to a tape recorder malfunction in the afternoon.

4. February 28, 1985

A single, deep SSQ-57 buoy was deployed and monitored by both the MASTF van and a P-3 aircraft. A log was kept of local shipping traffic and the influence on

approximately 8, 17 and 25 km from the recording site at the Presidio (Figure 2.1). These stations were selected for two primary reasons: all three sites were within reception range of the recording station, and the effect of changing water depth on ambient noise could be studied. Station 1 was situated along the slope of the continental shelf. The water depth in this region rapidly increases from 1280 to 1830 m over 2 km. Station 3 is located in a region where the water depth is more constant, increasing from 1280 to 1500 m over 5 km.

During the at-sea tests measurements were made of the parameters that most affect ambient noise. These measurements include wind speed or sea state, shipping traffic, temperature and sound speed profiles. Wind speed and wave height were estimated by the ship's master during the December tests. During the February tests, wind speed was measured by the ACANIA's anemometer utilizing the Data Acquisition System (DAS), and a hand-held anemometer. The ACANIA's anemometer is located on a mast at 14.5 m elevation. The hand-held model was used at either 10 or 12 m. The ship's radar was used to detect shipping traffic. On February 28 a Navy P-3 was helpful in determining the type of ship and its course and speed. The temperature profile and sound speed profile at the different locations were measured using XBT and XSV probes. Measurement and environmental details associated with each at-sea test period are outlined below.

1. <u>December 11, 1984</u>

At Station 1 a deep and a shallow SSQ-57 sonobuoy and a shallow SSQ-41B sonobuoy were deployed. At Station 2 a deep SSQ-41B was deployed. At Station 3 both a deep and shallow SSQ-57 were deployed. Data derived from the deep sonobuoy at Station 3 was useless due to radio interference during the entire period of operation.

the analysis bandwidth and filtering required to achieve the 25 Hz window about the selected center frequency. This results in a noise correction factor of 14 dB which is computed internally. Care must be taken to record ambient noise readings in a slow and deliberate fashion, because the internal circuitry uses a 10 sec integration time to compute the noise level. The meter must be allowed to stabilize when switching from one center frequency to another to accurately measure the noise spectrum level.

Prior to recording the buoy signals, a calibration of the receivers and tape recorder is required. An internally generated 1 kHz tone modulated at 75 kHz is routed to the receivers and tape recorder tracks. For proper calibration a 2V rms output is expected (West, 1984). Individual receivers were noted to have different receiver sensitivities. Individual tracks on the tape recorder also had minor variations in their sensitivities. This calibration recording enabled a correction factor to be computed and employed to reconstruct the noise levels seen throughout the experiments.

The sonobuoys used for the ambient noise analysis included the SSQ-41E, SSQ-57A and SSQ-57XN5. Typical calibration curves for these sonobuoys are included in Appendix A of this thesis. Military specifications require that manufacturers meet this calibration criteria (NAVAIRSYSCOM, 1983). The buoys were set either shallow (18 m) or deep (305 m) for long life (8 hours).

B. EXPERIMENTAL TESTS

Three different locations were investigated for the ambient noise analysis. Their geographic positions are 36°40'N, 122°05'W; 36°40'N, 122°11'W; and 36°40'N, 122°17'W, respectively. These positions correspond to locations

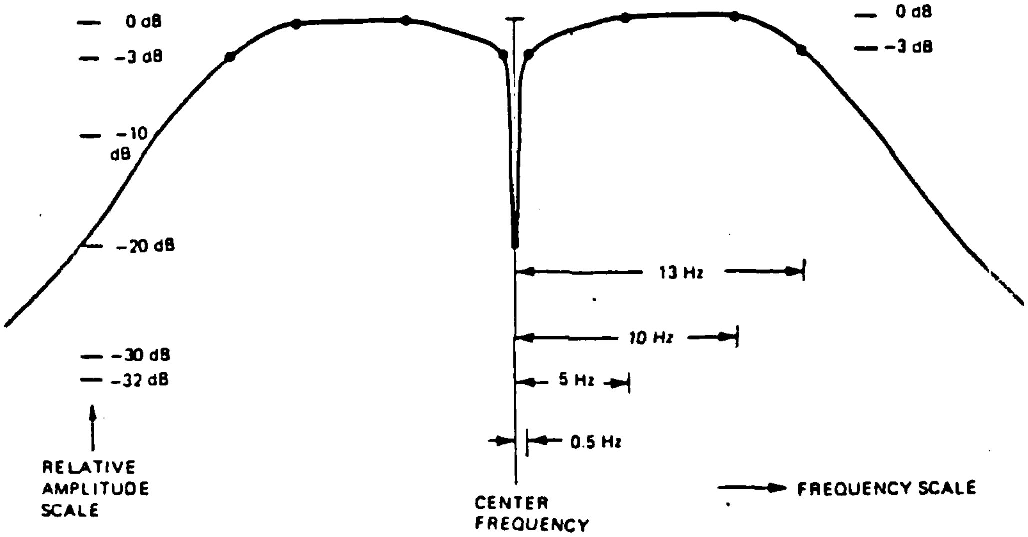


Figure 2.3 **The ASNI analysis bandwidth configuration is shown above** (Ezell, 1981).

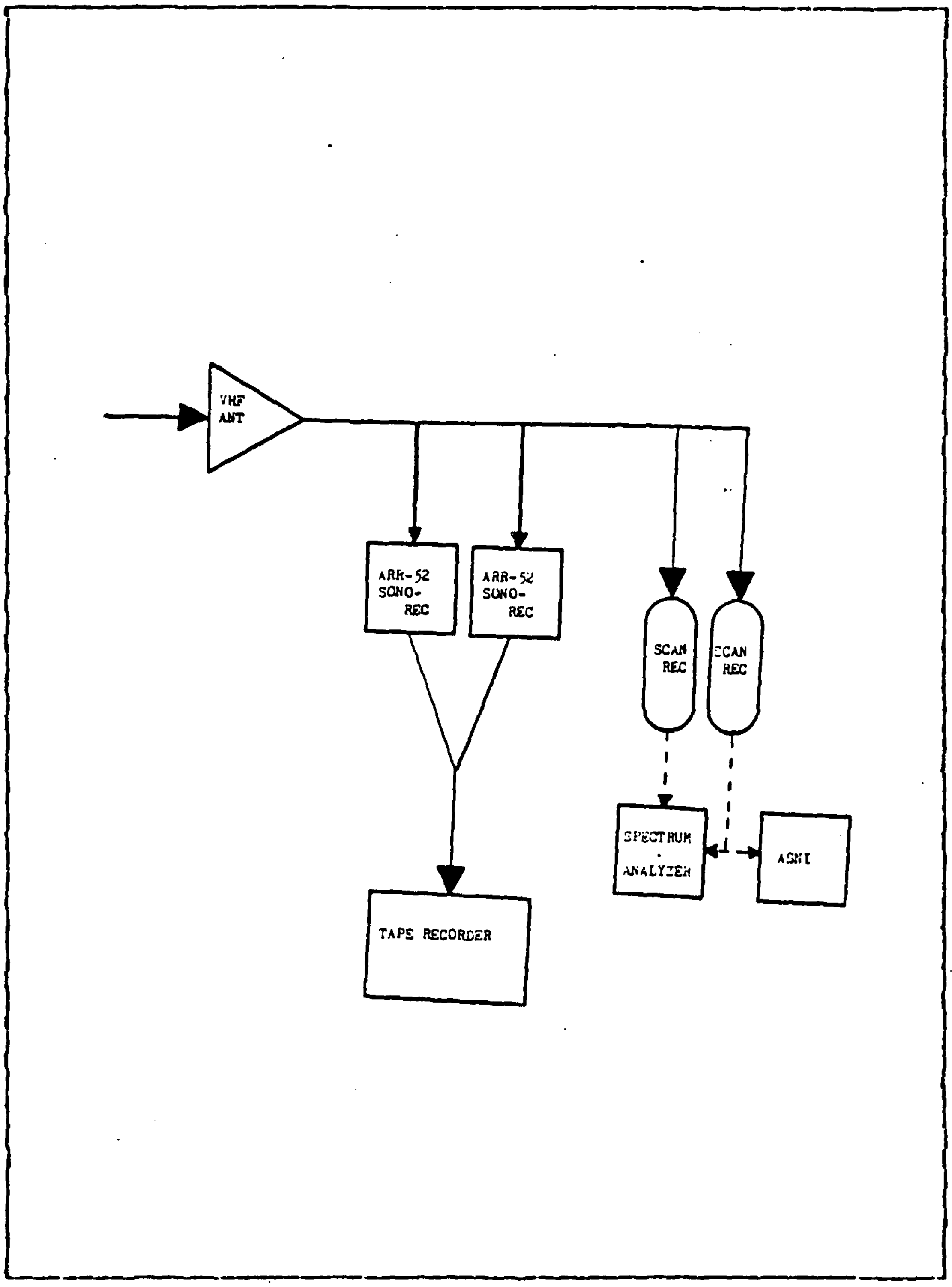


Figure 2.2 The incoming VHF signal is routed as shown above.

conditions were recorded aboard the ACANIA. Significant local shipping was detected by radar and a surface plot of shipping contacts was generated. Bathythermograph and sound speed probes were launched to determine the temperature profile to a depth of 460 m and the sound speed profile to the sea floor.

The MASTF van was used as the recording station for the acoustic ambient noise data. Figure 2.2 is a block diagram of the routing of the incoming signal. The MASTF van has a 12 m VHF antenna which can be hydraulically elevated above the roof of the van. The van is equipped with an ARR-52 receiver consisting of four, 31-channel receivers. It is also equipped with two separate digitally tuned scanning receivers. The VHF signal could be distributed to either or both of these receivers. An additional ARR-52 was installed to yield a total monitoring capability of 10 buoys. Each channel of standard audio output was then routed to a Honeywell 5600E 1-inch, 14-track tape recorder, and/or intercepted for measurement on the Ambient Sea Noise Indicator (ASNI).

The tape recorder was equipped with seven tracks of FM cards, one of which was used for a time code generator. Seven AM direct-record tracks were available, though one was reserved for servo control. One track was reserved for general comments and to complement log keeping.

The ASNI, manufactured by Sparton Electronics, is used by Navy P-3 aircraft to measure the ambient noise from AN/SSQ-57 or AN/SSQ-41B sonobuoys. An ASNI was installed in the MASTF van to measure the ambient noise at various times throughout the tests. ASNI levels are calibrated in decibels in a 1 Hz band relative to 1 μPa^2 for the omnidirectional noise level. The center frequencies for the ASNI are 50, 100, 200, 440, 1000 and 1700 Hz. The analysis bandwidth is 25 Hz. Figure 2.3 is an illustration of the structure of

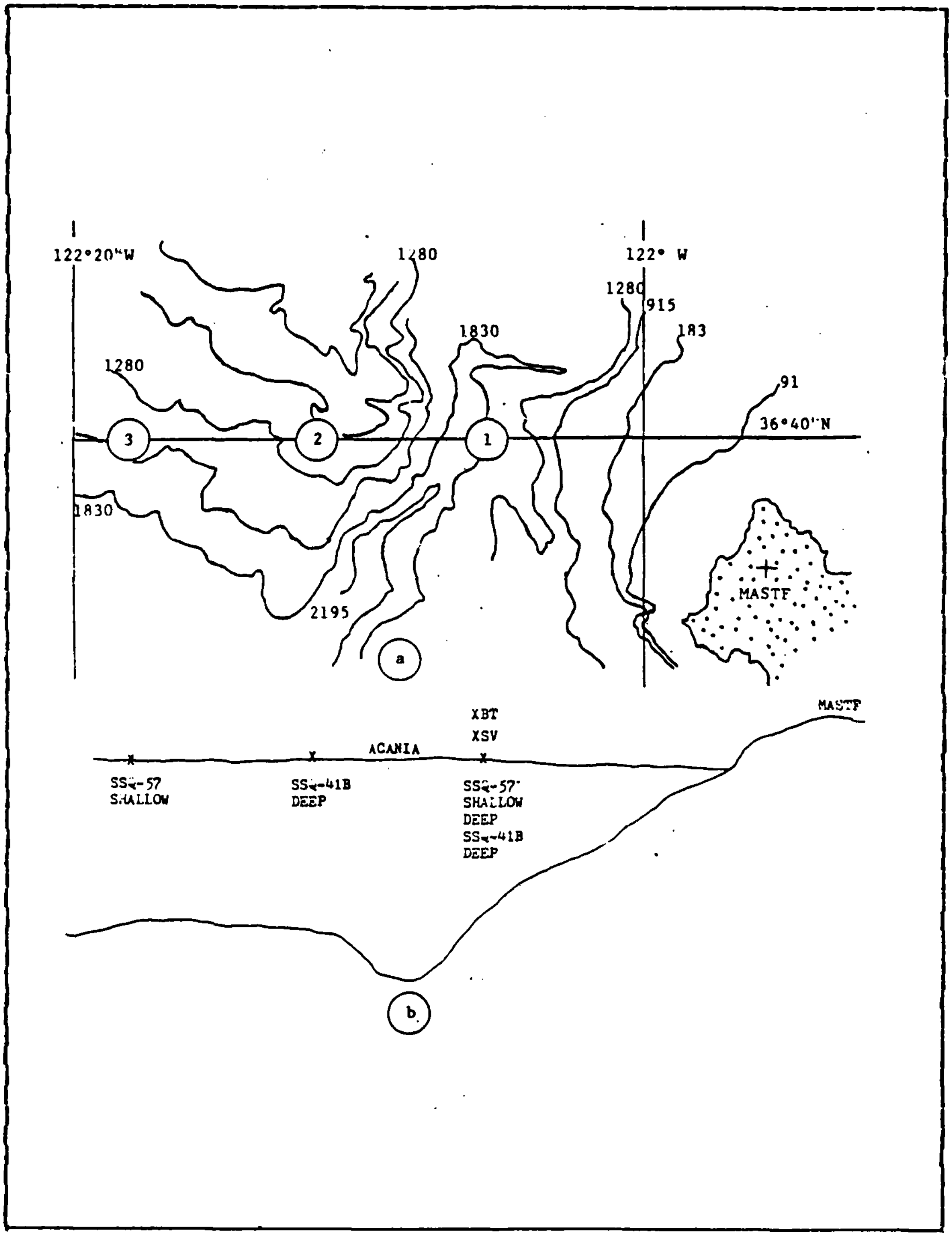


Figure 2.1 This sketch depicts (a) the water depth (in meters) and (b) the measuring systems used at each station.

II. EXPERIMENTAL PROCEDURE

The acoustic ambient noise experiments consisted of two at-sea exercises, one conducted on 11-12 December 1984 and the other 26-28 February 1985. The primary goal of each at-sea period was to conduct acoustic experiments concerning ambient noise and vertical line array (VLAD) acoustic measurements. Only procedures directly related to the collection of ambient noise data are described in this report. Supporting units included the research vessel "ACANIA" and the Mobile Acoustic Test Facility (MASTF) van. Prior to performing the at-sea tests the DANES and ICAPS forecast models were each run to predict the ambient noise for this location.

A. EQUIPMENT SET-UP

For each exercise the MASTF van was moved to a location at the Presidio of Monterey at a height of approximately 215 m above mean sea level. This location provided an unobstructed view of the sea-test sites and provided a line of sight VHF receiving capability to about 50 km. Due to the rough seas experienced in December, considerable RF fading was experienced beyond a range of 30 km. Figure 2.1 illustrates the relative positioning of the participating units.

The ACANIA was used both as a buoy launching platform and a communications station. In support of the VLAD measurements, a low frequency J-15 narrow band projector was deployed. This sound source contaminated the ambient noise levels recorded at certain frequencies and will be noted when it influenced the noise field. Wind and swell

wind-dependent spectrum. Since the NADS buoy will be unattended during operational use, an ambient noise value at a wind-dependent frequency which is contaminated by an individual ship will lead to faulty predictions of surface wind speed. This effect will be addressed to determine the farthest range at which an individual ship can contribute to the wind-dependent spectrum.

Finally, the effects of changing water depth will be studied to determine the influence of the sound speed profile and coastal effects on ambient noise. The relatively shallow water off the coast (compared to the open ocean) undoubtedly has an effect on the ambient noise measurements.

This thesis examines the ambient noise measuring capability of the NADS buoy. The acoustic system design defines the parameters of the analysis. The purpose of the thesis is to establish a framework for the testing of the NADS buoy upon completion. It will be tested off the Monterey, California coast along with other systems for comparison. The performance of the buoy will be analyzed in a region 10-25 km from shore in water depths averaging 1830 m. This area is close to the continental shelf. Because the buoy is designed for open ocean use, unattended and free floating, this pre-analysis of the coastal shipping and wind effects is needed prior to actual testing.

The Navy is primarily interested in the ambient noise at a specific frequency for application to the sonar equation. This infers that measurements be made using a narrow band approach. Such is the case with the utilization of the ASNI to measure ambient noise. However, the NADS buoy will measure ambient noise spectrum levels using 1/3 octave band filters. A comparison will be made between ambient noise spectrum levels measured using a narrow band and a 1/3 octave band approach in order to determine whether AN measurements agree using either method. If the methods are comparable, then the NADS may be useful to the Navy as a historical data base or a real-time sensor.

In previous studies (Wenz, 1962; Perrone and King, 1975), a direct correlation between wind speed and ambient noise has been shown to exist. Watts and others (Watts et al, 1978) have shown that the surface wind speed can be estimated based upon acoustic ambient noise observations. It is anticipated that the NADS buoy will be able to perform a similar function.

The wind and ship influence on ambient noise will be studied to enable the prediction of surface wind speed from ambient noise. Individual ship influences can dominate the

1. suspension of a hydrophone directly from the attending boat,
2. using a positively buoyant cable to attach a float to the standard PRL drifter hull and suspending the hydrophone string from the float,
3. a floating line approach,
4. a sonobuoy suspension.

The boat suspension showed complete saturation of the hydrophone preamp while the others showed marked improvement. A refined version of the floating line approach, optimized for sensor component configuration, has been proposed. This type of suspension is expected to decouple the buoy from vertical oscillations due to wave motion.

B. OBJECTIVES

Predicting the ambient noise levels in remote ocean regions is of great concern to the Navy. More precise estimates are needed to assess the performance of ASW systems. Prediction models such as the Directional Ambient Noise Estimation System (DANES) have been developed to accomplish this task. The familiar Wenz curves (Wenz, 1962) and its modifications (Naval Weather Service Center, 1972) have also been used to predict the ambient noise. In order to measure the ambient noise in-situ, Navy P-3 aircraft use the Ambient Sea Noise Indicator (ASNI). The ASNI uses SSQ-57 or SSQ-41B sonobuoys to measure the ambient noise at 50, 100, 200, 440, 1000 and 1700 Hz. The NADS buoy is proposed to complement the P-3 data acquisition effort by providing continuous updates of the ambient noise. Such data could also provide an historical data base over large ocean regions or could be used to support "real-time" forecast models of ambient noise.

TABLE I

1/3 Octave Band Center Frequencies
and Respective Passbands

CENTER FREQ. (Hz)	1/3 OCTAVE PASSBAND (Hz)
5	4.5 - 5.6
10	8.9 - 11.2
25	22.4 - 28.2
50	44.7 - 56.2
100	89.1 - 112
160	141 - 178
250	224 - 282
400	355 - 447
1000	891 - 1120
1600	1410 - 1780

Table I. These bands encompass the frequency range from 5 Hz to 2 kHz. The 2 kHz limit is imposed by the useable frequency response of the bender hydrophone. The 11 bands were selected to cover the spectrum of interest to the Navy and research establishments alike. The lower frequency bands up to 100 Hz will likely contain predominately shipping noise. Those bands greater than 100 Hz will contain local shipping as well as wind-dependent noise effects. In the infrasonic spectrum seismic activity and other effects on the noise field may be studied. In order for this to be possible, the decoupling mechanism must succeed and therefore only 2 bands at 5 and 10 Hz have been selected.

The SYNARGOS ambient noise measuring buoys were not subject to vertical oscillation of the hydrophones due to wave motion. With the NADS the surface buoy becomes a surface follower and unless the sensors are decoupled from the buoy, they will experience vertical motion much like that of the buoy itself. These hydrostatic pressure variations can serve to saturate the hydophones at low frequencies thereby making measurements of ambient noise suspect in this part of the spectrum. The hydrophone string must be isolated from this motion using a low, natural frequency suspension. In sonobuoys, partial isolation has been achieved using a soft elastic suspension with self deploying drogues to entrain water, producing a large virtual mass and damping vertical motion (PRI, 1984). This method is impractical for the drifting acoustic buoy program due to the number of fatigue stress cycles that the copper conductors and elastic members in the compliant section of the cable would sustain over the course of a year.

In an experiment conducted during 1983 by NPS and PRI (PRI, 1984), tests were conducted in the Santa Barbara Channel using four different hydrophone suspension configurations. These included the following:

5. air temperature, wind speed, barometric pressure at a height of about 1 m

The proposed meteorological and oceanographic measuring systems are all PRL standard commercial items. PRI has a long history of manufacturing buoys with all the above sensors using a general purpose signal processor/satellite transmitter system. The proposed ambient noise measurements are to be made using a variant of PRL's SYNARGOS system.

The SYNARGOS system was developed by PRL to collect ambient noise data in the eastern Arctic Ocean (PRL, 1982). It uses a single hydrophone to measure noise in one of eleven, 1/3 octave bands from 5-1000 Hz. The data generated from this buoy provide a long term statistical sampling of the noise field. When used in the Arctic, the hydrophone is suspended 30 m below the surface of the ice and can last for greater than 300 days. Every three hours the noise level is sampled and stored and four one-second bursts once every 60 sec are required to transmit 24 hr worth of data via satellite.

Unlike the SYNARGOS buoy, the NADS buoy will have two hydrophones tethered to the thermistor string at depths of 30 m and 305 m. These depths were selected to compare ambient noise levels at shallow and relatively deep depths and to enable a comparison with present fleet ambient noise-measurement sonobuoys. To ascertain the depth of the hydrophones and provide an indication of the effects of current shear, two depth-pressure transducers have been installed on the thermistor string at 16 m and 305 m. Each hydrophone will be of the bender type with a useable frequency from 0-2 kHz (PRL, 1984). As a free floating drifter, the buoy is designed for open ocean use with a life expectancy of one year.

The selected center frequencies for each of the eleven, 1/3 octave bands and their respective passbands are shown in

ambient noise determined. Contacts reported included a large tanker, an automobile ferry, a cargo carrier and a tug towing two barges. An hourly wind record was kept as in the previous experiment. Again, the acoustic projector was towed away from the sonobuoy.

C. DATA PROCESSING

Figure 2.4 is a diagram of the equipment set-up used to gather and analyze the ambient noise data. A computer program was written to process the data and define the analysis parameters. The HP 9836, through HP-IB connectors, controlled the spectrum analyzer. Ambient noise was measured using both a "narrow" band and 1/3 octave band analysis. Frequencies measured were at 50, 100, 200, 440, 1000, and 1700 Hz for narrow band processing and 50, 100, 200, 400, 1000 and 1600 Hz for 1/3 octave band processing. The 440 and 1700 Hz narrow band frequencies are included within the 400 and 1600 Hz 1/3 octave bands (Table I). For the sake of comparison, references will be made to the narrow band frequencies (i.e. 1700 Hz, etc.) throughout this study. These values were selected in order to compare with the ASNI measured noise levels.

1. HP 9836 Computer

The computer was programmed with operational commands to the spectrum analyzer to specify its mode of operation. Every 2 min the spectrum analyzer was commanded to record noise levels at each of the specified frequencies. Each noise level was then converted to an ambient noise spectrum level relative to 1 μPa using the following equation:

$$AN = RS + BS + SG + BW + CF + NL$$

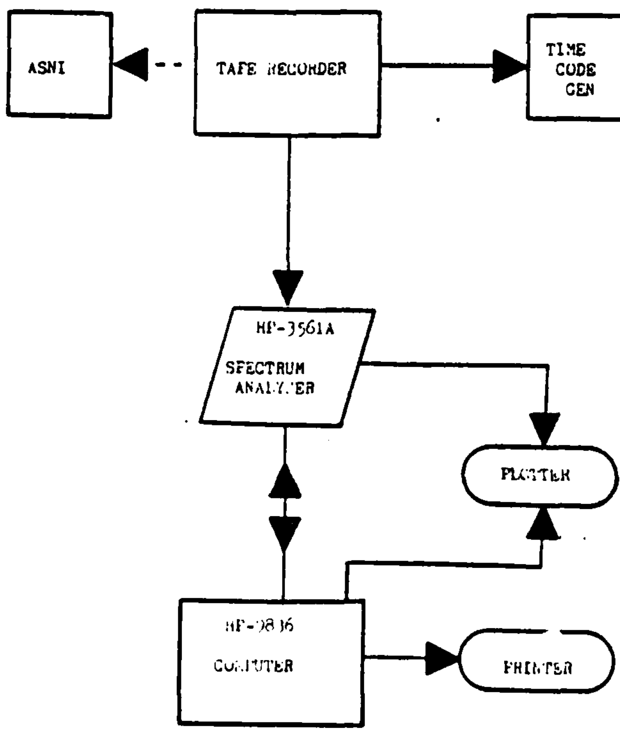


Figure 2.4 A block diagram is shown of the data processing set-up.

where RS is the receiver sensitivity, BS is the buoy sensitivity, SG is the sonic gain, BW is the bandwidth correction factor, CF is the calibration correction factor, and NI is the measured, uncorrected noise level.

The buoy sensitivity is given by 20 log {buoy sensitivity at the reference frequency}. For the SSQ-57, this expression becomes 20 log {106 dB re 1 μPa/19 kHz} or 80.4 dB. The receiver sensitivity is given by 20 log {receiver calibration factor}. This corresponds to 20 log {75 kHz/2 volts} or 31.5 dB. The sonic gain is obtained from the sonobuoy specification curves at a specific frequency (West, 1985).

Depending on the measurement scheme or the type of buoy used these values will vary. For example, the SSQ-57A has a buoy sensitivity of 80.4 dB while that for the SSQ-41B is 90.4 dB. Their sonic gains also vary with frequency. These values are derived from the buoy's specification curve as shown in Appendix A. The receiver sensitivity is a constant at 31.5 dB. The bandwidth correction factor for "narrow band" measurements was 9.7 dB. For 1/3 octave band measurements, this factor is dependent on the bandwidth about the selected center frequency. The calibration correction factor was determined from the calibration performed prior to the experiment.

The ambient noise level at each frequency was stored in an array every 2 min until the end of the noise record. Additional program subroutines performed tabular output of data, mean and standard deviation computations, and graphical plotting. The flexibility of this set-up allows for easy changes in analysis methods. A copy of the computer program is included in Appendix B of this thesis.

2. Narrow Band

The ambient noise was measured over a frequency spectrum of 0-2500 Hz. For this desired frequency span the HP-3561A spectrum analyzer is limited to 400 frequency bins for the desired frequency span. Due to this bin-width limitation a frequency resolution of 6.25 Hz was realized for this span. Most real-time spectrum analyzers use a Hanning window filter in their data processing routines. The Hanning filter provides for good frequency resolution but suffers from an amplitude uncertainty of -1.5 dB (Hewlett-Packard, 1984). With the Hanning filter implemented, the overall noise effective bandwidth was 9.375 Hz. Substituting this value in the bandwidth correction (10 log BW), a 9.7 dB correction was applied to yield the noise spectrum level. The AN levels were rms exponentially averaged using a 2 min weighting scheme. This averaging mode is a continuous averaging process that assigns more significance to recent data while older data die out in importance at a decaying exponential rate. An exponential weighted average is most useful when the process being measured exhibits relatively slow time variations and yet some averaging is desired (Hewlett-Packard, 1984). This is a valid assumption for measurements of ambient noise.

Forty time records were selected for averaging. After repeated trials, it was felt that this number provided a current indication of the ambient noise, while smoothing the minor fluctuations. An overload reject feature was used to exclude measurements of spurious noise sources from the accumulated average which overloaded the input circuits of the spectrum analyzer.

3. 1/3 Octave Band

The HP-3561A spectrum analyzer measurements are made in synthesized 1/3 octave bands. The filter bandwidth, center frequency, and bandshape meet ANSI Class III specifications (Hewlett-Packard, 1984). The spectrum analyzer establishes predefined measurement bands which are selectable through keypad entries. The selected measurement band for the 1/3 octave band analysis was 6.3 Hz to 10 kHZ. This band was selected to minimize the required data collection time for each averaging cycle. For example, a measurement band of 1.6 Hz to 2.2 kHz would have required 12.8 sec for data collection time vice the 3.2 sec for the 6.3 Hz to 10 kHz band. The design of the spectrum analyzer was such that to make measurements to 2500 Hz in a timely way, a band of 10 kHz was most reasonable. Standard 1/3 octave center frequencies between 6 Hz and 10 kHz are included within this band. As mentioned previously, an exponential weighted average is ideal for ambient noise analysis. Due to the longer data collection time, eight averages were selected for the weighting factor. To obtain a noise spectrum level, i.e., noise levels relative to a 1 Hz wide band, a bandwidth correction of 10 log (BW) was applied. The FM cards in the tape recorder have a flat frequency response to 2.5 kHz, so band levels above this frequency are not considered. The overload reject feature was used in this procedure also.

III. EXPERIMENTAL RESULTS

The DANES predictions of AN are shown in Figure 3.1 and Figure 3.2 for the two hydrophone depths on February 26. Since DANES is a large-area average, the predictions are identical at all 3 sites. This version of DANES does not include World Meteorological Organization (WMO) shipping in its computation of ambient noise. The tranmission loss model incorporated in DANES is ASTRAL. ASTRAL provides an averaged transmission loss and does not forecast convergence zone propagation of ship-generated noise. The DANES omni-directional AN at 50 Hz was predicted to be 63.4 dB. This value was 20 to 30 dB less than that experienced. This may in part be due to the aforementioned characteristics of the DANES model. The noise variability is also high due to the relatively shallow water and the fairly large amount of shipping lane traffic. The ICAPS predictions were 78 dB at 50 Hz, 76 dB at 300 Hz, 64 dB at 850 Hz, and 60 dB at 1700 Hz. The ICAPS prediction of 78 dB at 50 Hz was closer to the measured noise levels but still quite low. The AN at 1700 Hz using either prediction model was much closer to the observed values. According to DANES the shipping noise arrives primarily from the northwest, which would coincide with shipping traffic centered near San Francisco. It is apparent that both models fail to accurately predict the AN for low frequencies but are quite good at higher frequencies where wind and sea state are the dominant factors.

A. ONE THIRD OCTAVE BAND VS NARROW BAND

Ambient noise levels were measured using two analysis methods, 1/3 octave band and "narrow band". During the

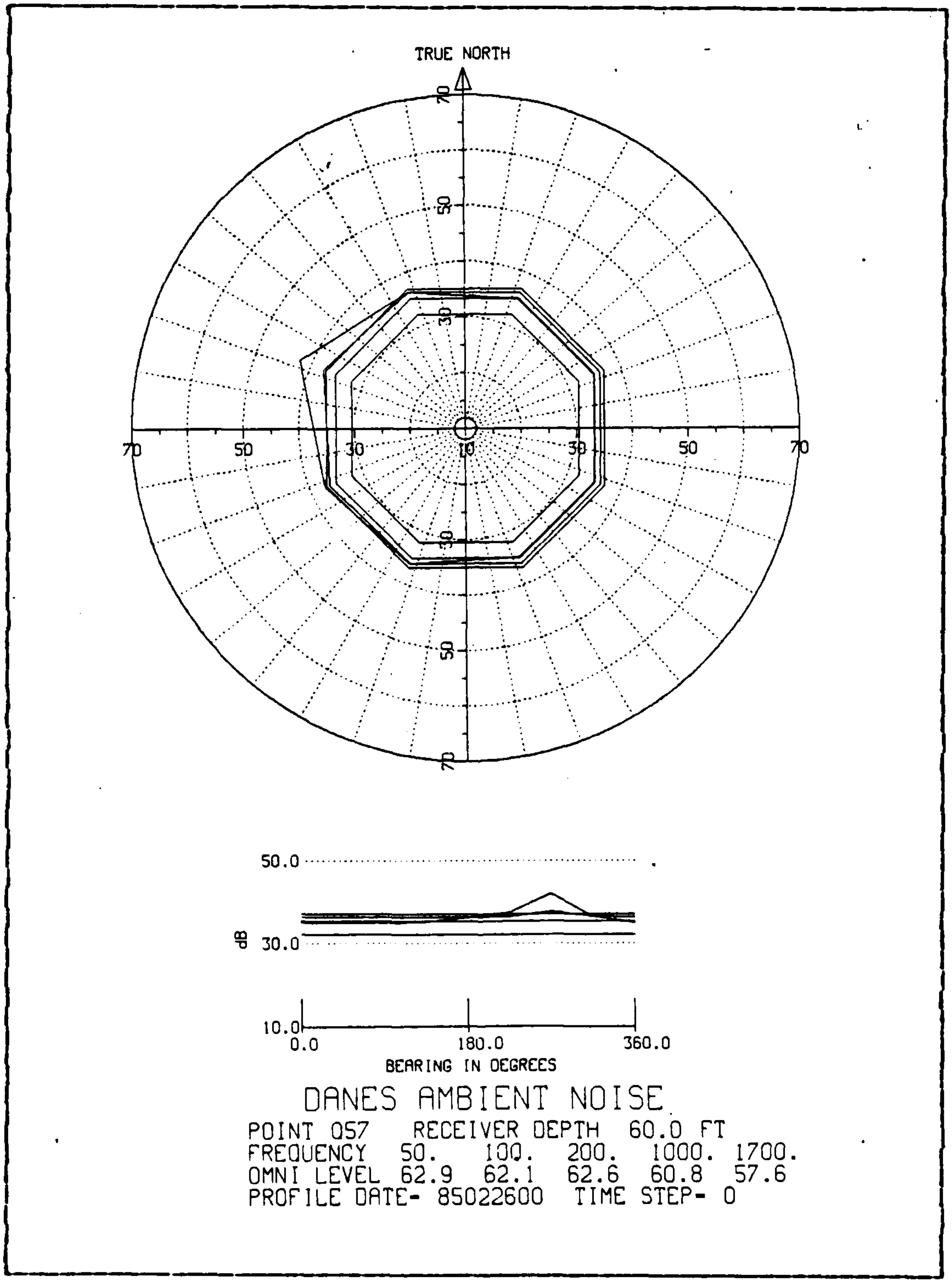


Figure 3.1 The DANES prediction of AN is shown for a shallow buoy.

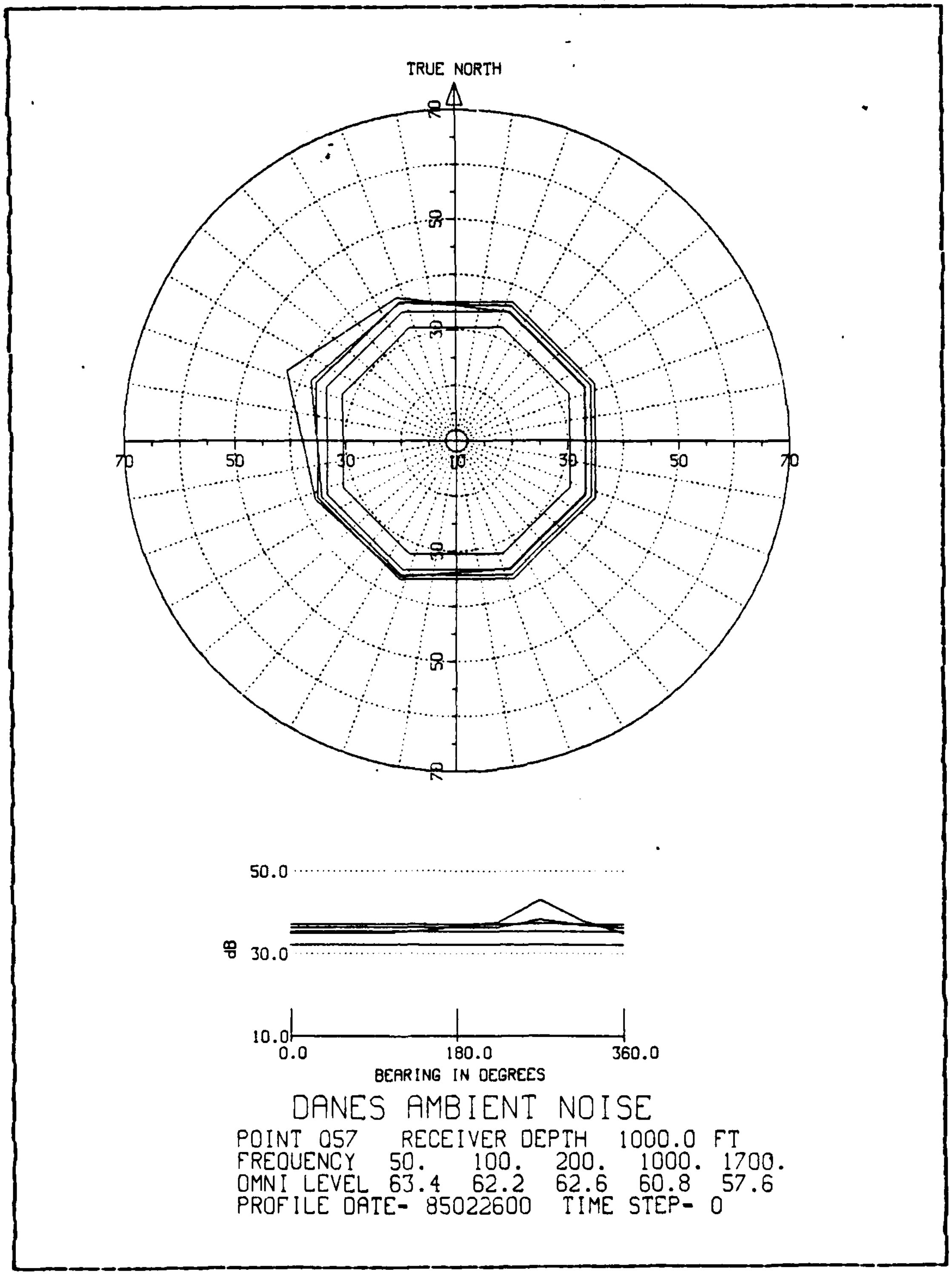


Figure 3.2 The DANES prediction of AN is shown for a deep buoy.

at-sea measurement periods, ambient noise was measured on the ASNI and logged. A 1/3 octave band analysis was done to prepare for eventual comparison with and testing of the NADS buoy and also to compare with levels acquired through a narrow band analysis of the data. Though, in actuality the bandwidth of the narrow band analysis is not 1 Hz (about 9 Hz instead), the bandwidth is less than that provided by the ASNI (25 Hz). However, the noise levels were corrected to a 1 Hz band in each case.

Ambient noise levels recorded from the ASNI can be compared to those measured using 1/3 octave filters. At a center frequency of 100 Hz for a 1/3 octave band analysis, the bandwidth is about 23 Hz. This is close to the analysis bandwidth (25 Hz) of the ASNI. It would be expected then that noise values at this frequency would be comparable. This is indeed the case as shown in Table II.

At this frequency the AN differs by at most 2 dB. The differences may in part be due to the way the AN was measured in each case. The ASNI readings were more of an instantaneous value while the 1/3 octave band values were averaged over a 2 min period. No record was kept of how much the ASNI readings varied during the measurement cycle. The 3-4 dB difference at 1000 Hz is not fully understood. Such a large difference would not be expected when local ships were absent. The 1/3 octave band values compare well with the narrow band measurements made in the laboratory but not so well with the ASNI values. It is possible that the ASNI meter was out of calibration at this frequency. For the other frequencies, the agreement is quite good.

Most of the measurements show that the AN at 50 Hz is greater using the 1/3 octave band approach. This can be attributed to the smaller bandwidth at this frequency and the spectral contribution to the band. Above 100 Hz, as the bandwidths grow, the differences are not too great as long

TABLE II

Ambient Noise Measurements
ASNI vs 1/3 Octave Band

TIME	METHOD	50 Hz	100 Hz	200 Hz	440 Hz	1000 Hz	1700 Hz
1250	ASNI	87.0	75.5	69.5	63.0	60.0	58.0
	1/3	89.0	77.2	70.5	65.1	61.7	57.8
1324	ASNI	88.5	74.0	67.0	64.5	59.5	58.0
	1/3	89.6	73.5	67.4	66.4	62.4	57.9
1334	ASNI	86.0	74.5	69.0	70.0	60.5	58.5
	1/3	90.1	74.5	68.8	68.2	61.7	58.8
1340	ASNI	86.5	73.0	68.5	66.5	60.5	58.0
	1/3	87.4	74.7	68.3	67.3	63.2	58.6
1447	ASNI	85.0	73.0	67.0	65.5	60.0	57.0
	1/3	87.9	74.5	67.2	65.7	64.2	58.5

as spectral components of individual ships are not present. If this is the case, the comparison is more complex. The ASNI will indicate higher AN levels if the particular ship has high source spectrum levels at the center frequencies; otherwise, the 1/3 octave bands may contain sufficient energy to yield greater values of AN.

Table II will be used to illustrate this point. At 1322, a large ship was sighted at 12 km heading in a direction away from the sonobuoys. The 1324 ambient noise measurement shows good agreement between the ASNI and 1/3 octave band methods at 50 and 100 Hz. The 440 and 1000 Hz values differ by 2-3 dB with 1/3 octave band values being greater. As the ship moves away, it would be expected that the noise spectrum levels would decrease with increasing range. At 1334 the 50 Hz and 440 Hz values differ the most. Due to the narrower band at 50 Hz, the 1/3 octave band value was higher. The ASNI recorded a higher level at 440 Hz since the energy within its processing bandwidth was greater.

The processing of the noise recordings using the narrow band and the 1/3 octave band methods resulted in tables of AN levels measured every 2 min for the duration of the recording cycle. A sample table is located in Appendix C. Each recording tape provided approximately 45-60 min of noise data. The gaps in the record of AN are due to the time required to mount a new tape, or changes made in the monitoring of particular sonobuoys.

A comparison of the two analysis methods indicates that the results show consistent agreement. Table III shows that differences in mean noise levels for the two analysis methods over comparable time periods are within 2 dB of each other. For most measurements the differences are less than 1 dB. The ACANIA's influence is seen on the 26th of February from 1142 to 1200. Significantly higher AN values at all frequencies are seen.

TABLE III

Mean Noise Levels for Same Time Periods- Narrow Band vs 1/3 Octave Band

26 FEB 1985

SSQ-57 SHALLOW

TIME	METHOD	50 Hz	100 Hz	200 Hz	440 Hz	1000 Hz	1700 Hz
1142 TO 1200	NB	93.4	89.5	79.9	77.2	66.8	61.0
	1/3	93.3	89.2	80.5	76.0	67.3	62.8
1202 TO 1232	NB	90.3	79.6	72.7	73.5	62.7	58.6
	1/3	89.8	79.8	72.5	69.0	63.2	59.8
1247 TO 1343	NB	90.9	76.5	71.2	69.1	63.9	60.2
	1/3	91.4	76.5	70.3	67.9	63.8	61.0
1357 TO 1451	NB	91.1	77.5	71.4	69.7	63.4	59.9
	1/3	91.8	78.2	71.5	68.6	63.9	60.9

28 FEB 1985

SSQ-57 DEEP

TIME	METHOD	50 Hz	100 Hz	200 Hz	440 Hz	1000 Hz	1700 Hz
1225 TO 1309	NB	103.3	83.2	71.6	67.0	60.4	54.3
	1/3	104.0	84.1	72.3	67.1	61.0	55.8
1334 TO 1432	NB	89.2	80.6	76.3	70.8	64.0	57.0
	1/3	89.6	80.3	76.7	71.3	63.9	58.4
1442 TO 1538	NB	90.9	86.6	77.9	68.7	64.3	57.5
	1/3	91.1	85.9	77.7	68.2	63.8	58.7
1550 TO 1616	NB	86.7	87.6	74.9	68.2	66.2	61.7
	1/3	86.7	88.0	75.5	70.8	66.8	63.7

To illustrate how well these two methods relate over time, the AN at 50 Hz is plotted as a function of local time for a single sonobuoy using a 1/3 octave band and a narrow band analysis (Figure 3.3). The traces are virtually identical and all major variations can be seen equally well. Point "A" identifies the passage of a large cargo ship which was reported travelling at a speed of 7 m/s. A super tanker travelling at 6 m/s is recorded at point "B". The ACANIA passed the measuring sonobuoy at point "C". Finally a tug which was towing two barges is shown at point "D".

The standard deviations of the noise levels indicate good agreement between both methods. The 1/3 octave levels generally produce smaller standard deviations (<0.5 dB) for the same time periods. This is due to the larger bandwidths of 1/3 octave processing. Spectral components of fairly large values are required to affect a significant change in standard deviation. This is the case when individual, local ships contribute to the noise field. When this occurs, 1/3 octave band standard deviations are greater for those frequencies which are normally considered to be in the wind-dependent regime (1700 Hz). This can be attributed to the spectral contribution of the local shipping, which shows contributions even at frequencies greater than 1000 Hz (see, for example, Figure 3.9). Table IV shows these relationships.

B. SHIPPING EFFECTS

The effects of shipping on the measured AN is assumed to be composed of two components, individual ships and distant merchant shipping. The modified Wenz curves shown in Figure 3.4 categorize the shipping noise into separate regimes based on the shipping density. The AN values at 50 Hz and 100 Hz for the different shipping regimes are shown in Table V.

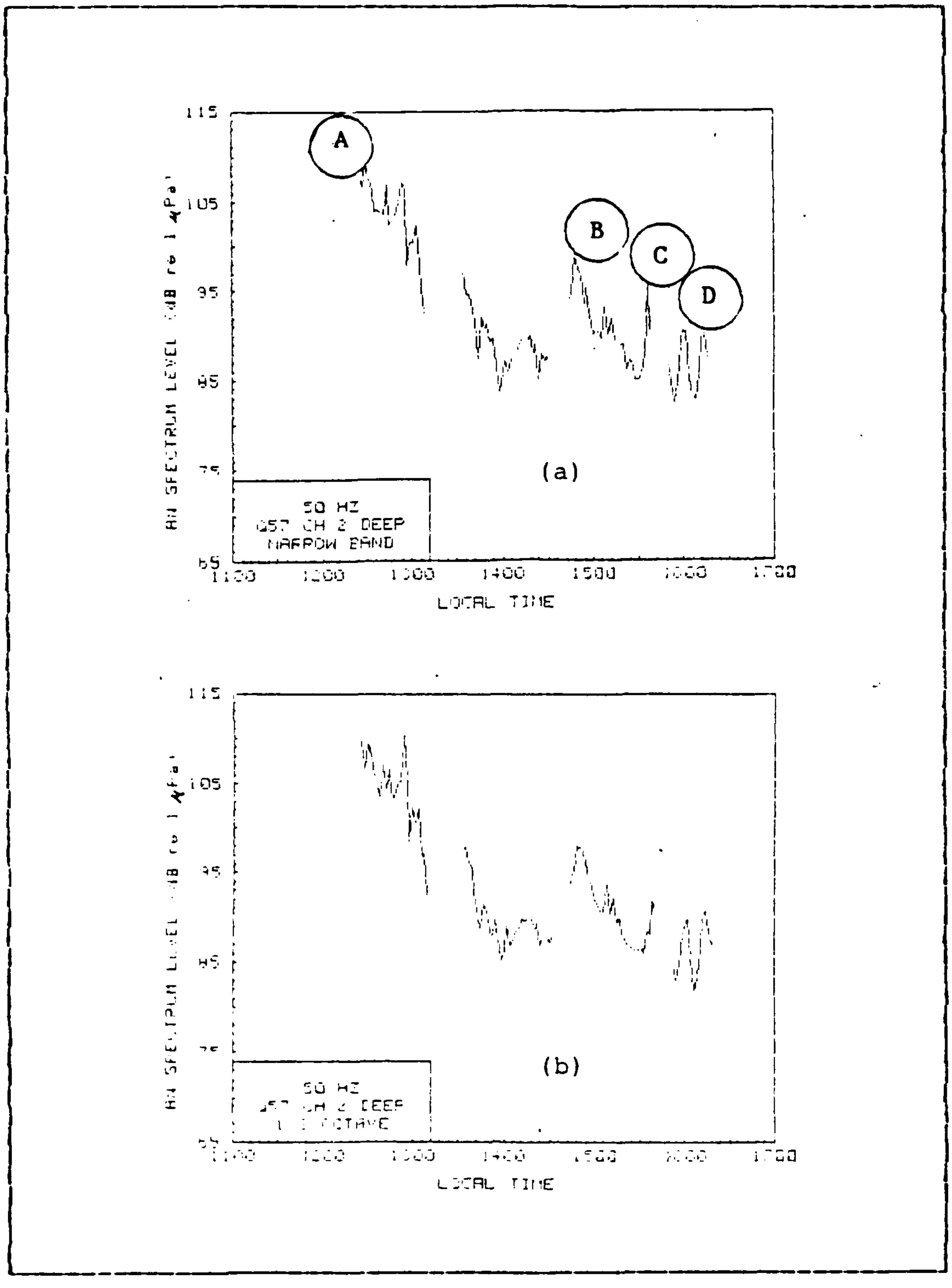


Figure 3.3 A comparison is shown of the AN at 50 Hz (a) narrow band, (b) 1/3 octave band.

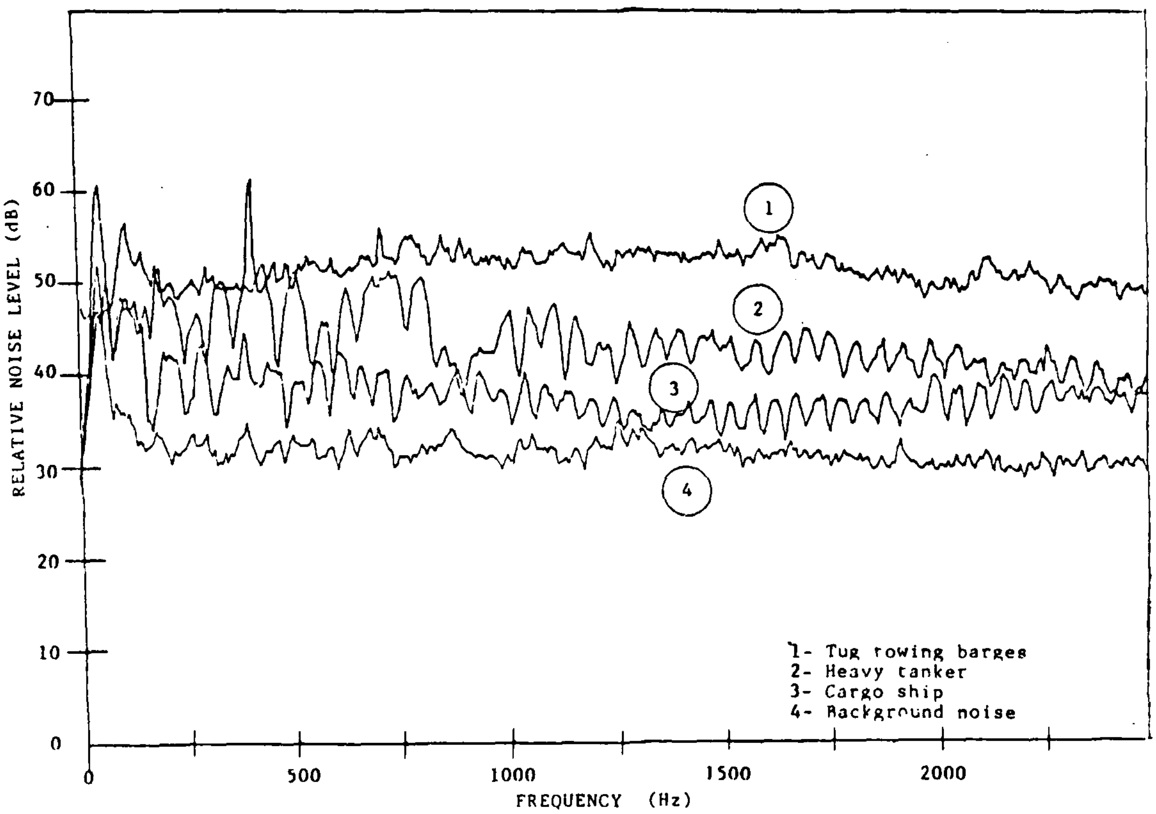


Figure 3.9 The uncorrected noise level of several individual ships is shown for a deep hydrophone.

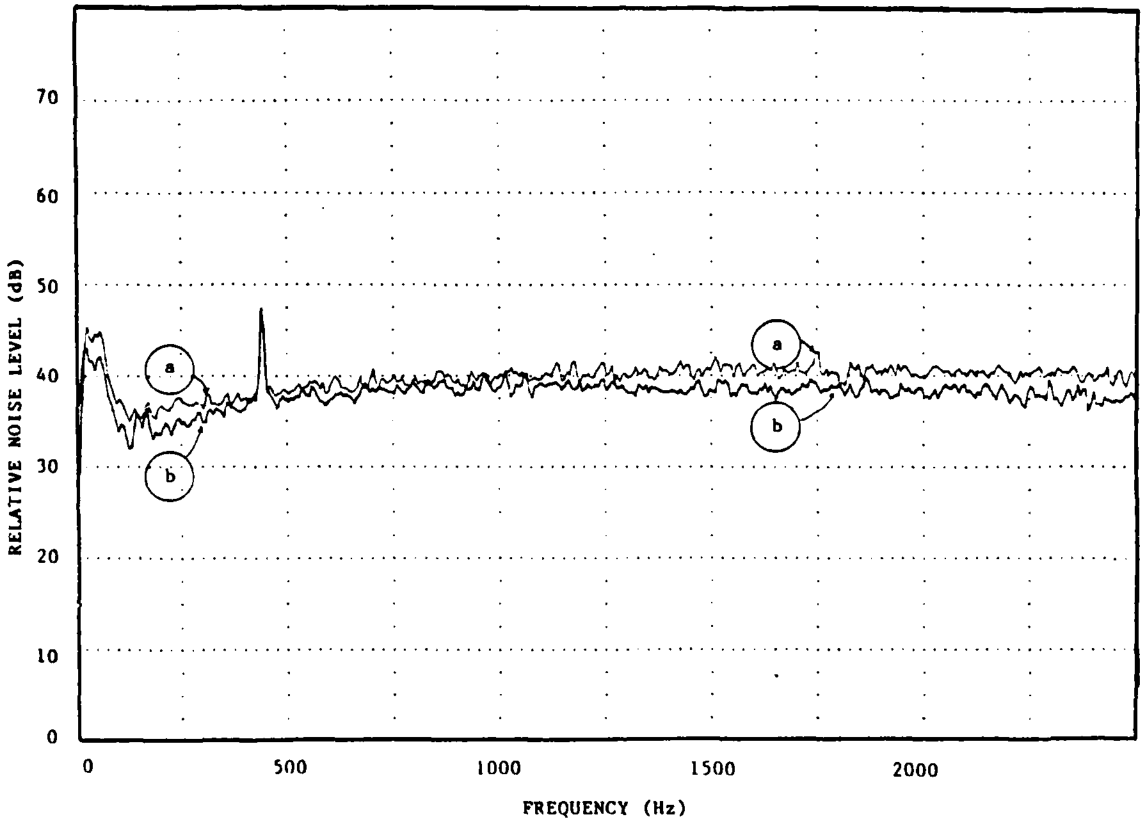


Figure 3.8 The uncorrected noise level is shown for (a) shallow and (b) deep buoys (ACANIA not in the area).

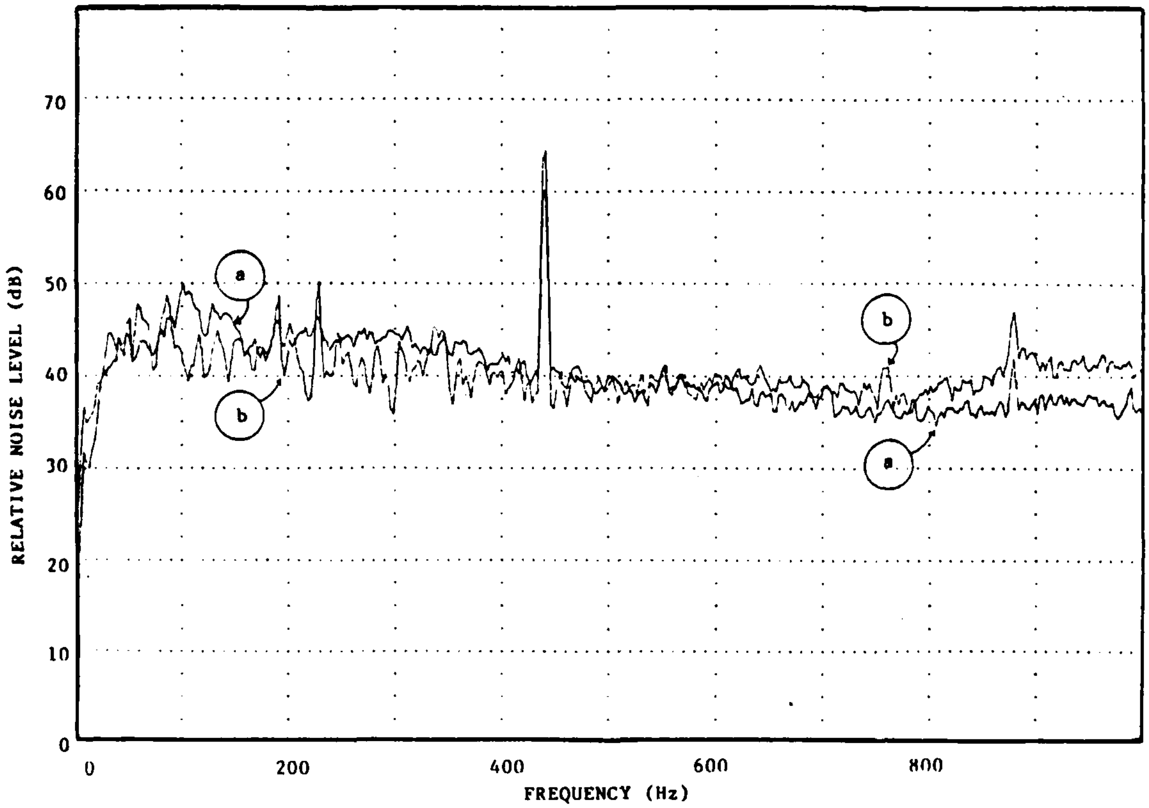


Figure 3.7 Simultaneous measurements of uncorrected noise level at a (a) shallow and a (b) deep buoy.

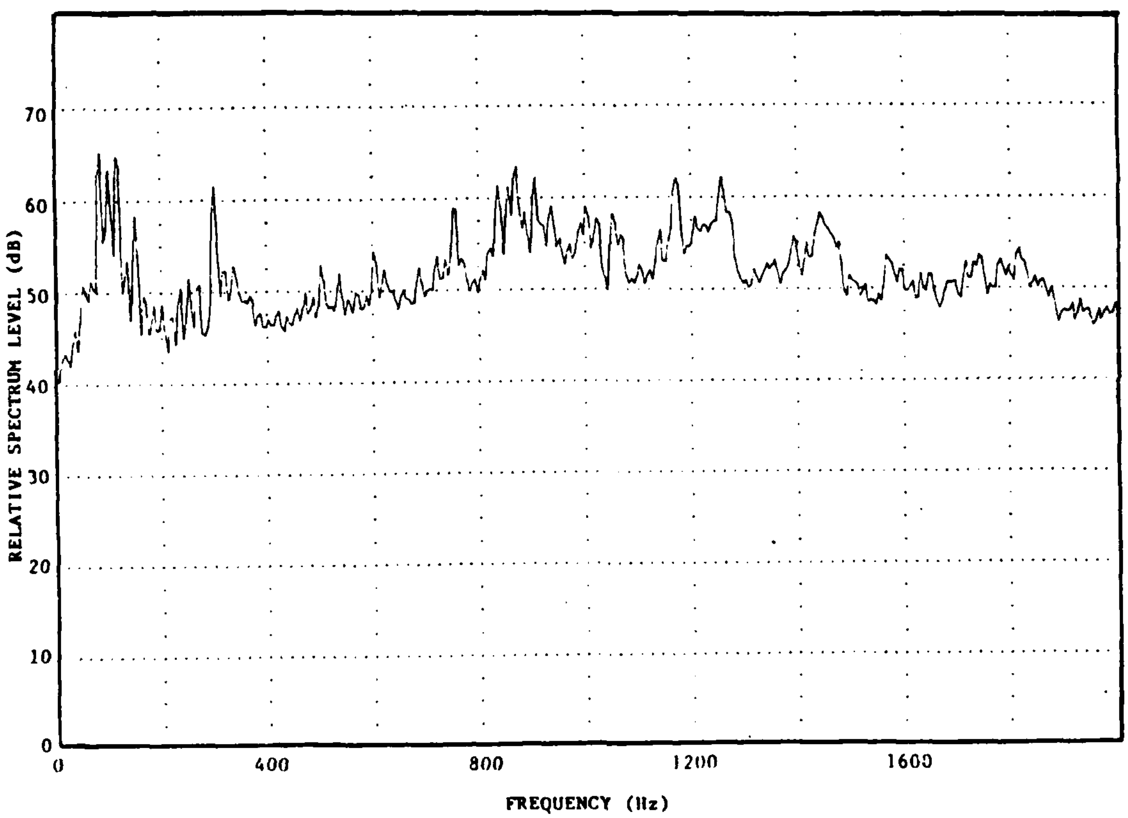


Figure 3.6 The ACANIA frequency spectrum is shown based upon a 100 m passage from the measuring sonobuoy at Station 1.

To support this hypothesis, a surface duct transmission loss model is offered. The generalized source spectrum level (Ross, 1976) for merchant shipping at 1700 Hz is assumed to be 132 dB. The transmission loss includes 10 log (transition range), 10 log (range), and transmission loss due to scattering, leakage, and absorption. For the mixed layer depth observed (25 m), the resultant transmission loss is 77 dB. The source spectrum level of the individual ship is then 55 dB. This value agrees with the AN value extracted from Figure 3.4 for the individual ship case. This level, when added to the wind-generated ambient noise for wind speeds of 5 m/s (57 dB), results in a total AN at 1700 Hz of 59 dB, or an overall increase of 2 dB.

C. WIND EFFECTS

Wind speed was estimated by the ship's master during the December at-sea periods and measured during the February at-sea periods with anemometers. Table VIII shows the hourly measurements of wind speed on both anemometers. The hand-held anemometer tended to measure higher wind speeds. This could in part be due to less structural interference associated with the hand-held wind measurement and/or the 2-4 m difference in height between the two. The hand-held anemometer readings more closely approximated the estimates made by the ship's master and are used for the following analysis. More careful consideration will be given to the wind measurements in exercises to follow. This is intended as a preliminary investigation only.

The two frequencies considered for the analysis of wind-dependent noise were 1000 and 1700 Hz (Wenz, 1962). A comparison of measured AN at 1000 and 1700 Hz and values based on the modified Wenz curves for average wind speeds is shown in Table IX. The noise estimates for 19 m/s winds are

TABLE VII

ACANIA Spectrum Levels at Selected Frequencies at Different Ranges From a Shallow Buoy

DISTANCE	50 HZ	100 HZ	200 HZ	440 HZ	1000 HZ	1700 HZ
1 km	92.4	86.7	75.6	69.4	64.9	62.1
3 km	91.1	75.4	71.1	68.8	63.7	60.8
8 km	90.9	75.2	69.7	67.4	64.6	61.0
Modified Wenz	87	78	70	66.6	65	62

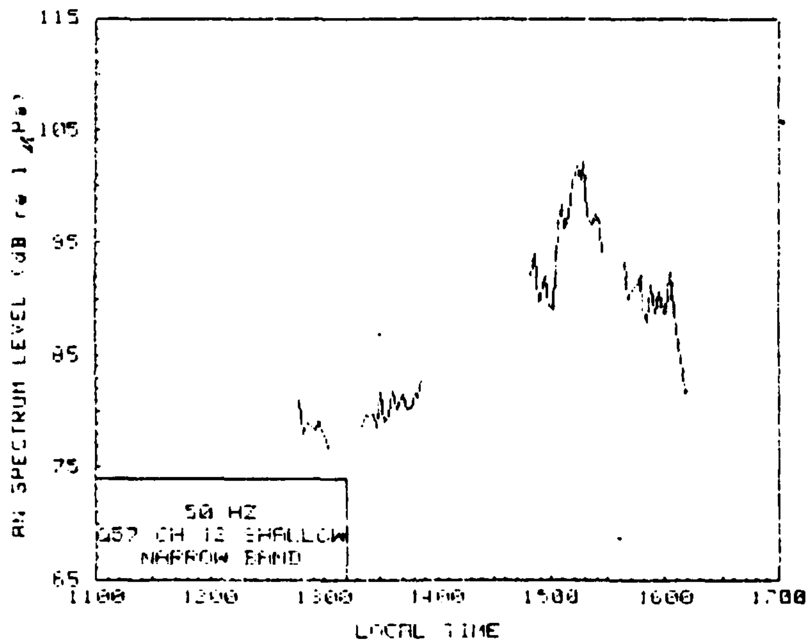


Figure 3.5 AN at 50 Hz is plotted as a function of time to illustrate the distant shipping variation at Station 1.

as shown by Arase and Arase (1967). The results agree in one case and not in another. Trapping of acoustic energy in the shipping-dependent frequency band in the surface duct is not a likely explanation as the low frequency cutoff for ducted propagation at this time of year is 1400 Hz. The deep hydrophone shows a more spectral nature to the noise. Apparently some form of direct radiation from the ACANIA to the shallow hydrophone is responsible for this oddity. When the ACANIA signature was not dominant, the shallow hydrophone measured higher levels of ambient noise for most frequencies. Figure 3.8 shows a mean difference of 1-2 dB for frequencies below 1250 Hz and a 2-4 dB difference for frequencies greater than 1250 Hz. The 50 Hz and 100 Hz AN levels were occasionally greater at the deep hydrophone. This was probably related to distant shipping arrivals as suggested by Arase and Arase (1967).

The uncorrected noise levels for surface traffic less than 15 km from a deep hydrophone are shown in Figure 3.9. Also shown is the background noise level when only distant shipping is present. From the above, one sees that nearby shipping affects the entire spectrum through 2500 Hz. Curve 1 is the noise spectrum from a tug towing two barges which passed the sonobuoy within a mile. Curve 2 is from a heavy tanker at 10 km and Curve 3 from a cargo ship at 13 km. The size and speed of the tanker and cargo ship are comparable. Though their acoustic signatures are different, it is apparent that the greater range reduces the ambient noise contribution by 8-10 dB for much of the spectrum. Based upon the ship tracks and AN measurements it was determined that individual ships at greater than 16 km no longer dominate the entire spectrum and can be considered as distant shipping. This distance is derived from the winter time SSP; it is likely to vary in response to the seasonal cycle in surface heating.

TABLE VI

Highest Noise Levels for Individual Shipping and Average AN Due to Distant Shipping

SHIPPING

	INDIVIDUAL SHIP		AVERAGE DISTANT SHIPPING					
			1100 - 1300		1300 - 1500		1500 - 1700	
	50 Hz	100 Hz	50 Hz	100 Hz	50 Hz	100 Hz	50 Hz	100 Hz
DEC 11	105.3	90.7	80	71.5	95	79	90	76
DEC 12	102.4	94.3	-	-	90	83	83	79
FEB 26	96.7	91.6	91	78	90	77	-	-
FEB 28	109.3	102.2	92	77	90	83	87	83

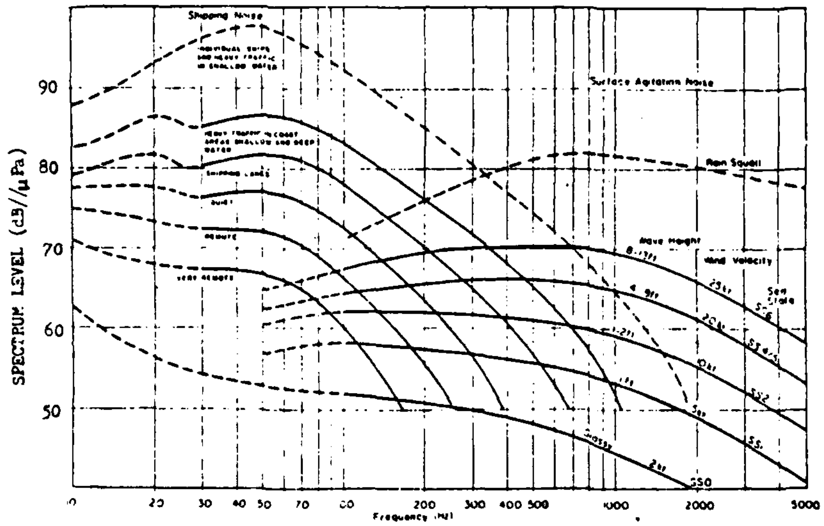


Figure 3.4 Modified Wenz curves which show shipping regimes and wind influences on the ambient noise (NWSC, 1972).

part be due to the generally heavier seas experienced in December.

The contribution of the ACANIA to the noise field was significant when the ship was within 3 km of the buoy. Table VII shows a comparison of the noise levels measured when the ACANIA was at 1 km, 3 km and 8 km distant. The last entry in the table is derived from Figure 3.4, which represents the distant shipping component as heavy traffic in shallow/deep water (NAVAIRSYSCOM, 1983). Figure 3.6 is an illustration of the frequency spectrum of the ACANIA. From Figure 3.6 and Table VII, it is evident that the effect of the acoustic signature of the ACANIA on the AN measurements is limited primarily to frequencies less than 1500 Hz and affects the noise field in a region of 3 km from the measuring buoy.

Since typical calibration curves were used to calculate the AN levels, the resultant noise levels can be 2 dB different between separate measuring sonobuoys. For this reason, any difference in levels less than 2 dB can be attributed to the variability in the receiving sensitivities of the measuring hydrophones. With this in mind, any comparison made between separate sonobuoys must account for this 2 dB variability.

This is the case when comparing the AN measured by the shallow and deep hydrophones. When the ACANIA was within 3 km, the noise levels measured at the deep and shallow hydrophones were frequency dependent but did not show consistency. On one occasion the shallow buoy recorded higher AN levels between 50-400 Hz while the deeper buoy was higher from 600-1000 Hz. This case is shown in Figure 3.7. On another occasion the deeper buoy recorded higher AN levels at all frequencies except 1700 Hz. One might expect that the AN would be higher at the deeper buoy for low frequencies (shipping) but lower for high frequencies (wind)

TABLE V

AN for 50 Hz and 100 Hz for Different Shipping Regimes Based on the Modified Wenz Curves

	INDIVIDUAL SHIP; HEAVY TRAFFIC IN SHALLOW WATER	HEAVY TRAFFIC IN COASTAL AREAS, SHALLOW AND DEEP WATER	SHIPPING LANES	QUIET
50 Hz	97.5	87.0	82.0	77.5
100 Hz	92.5	83.0	78.0	72.0

During the at-sea measurement periods, the 50 Hz noise levels varied from a high of 109.3 dB to a low of 76.2 dB. The high ambient noise level was recorded during a nearby ship passage. The low level was recorded when distant shipping could be categorized as "quiet" (Figure 3.4).

For the time frame of this analysis Table VI shows the highest levels of noise recorded for nearby shipping and the mean ambient noise due to distant shipping averaged over 2 hr intervals. The majority of the 50 Hz values fall within a range of 88-96 dB and were highest during the periods from 1400-1530 local time. After 1600 noise levels decreased into the mid-80 dB region. The 100 Hz noise levels were seen to follow the same trends. The most frequent range of values was 76-79 dB.

The measured individual ship AN levels are 5-10 dB higher than those predicted. The temporal variation of the shipping noise is consistent with the classifications described in Table V. All four shipping regimes were realized during the at-sea measurements. During the morning hours distant shipping could be categorized as "quiet" to "shipping lane"; in the afternoon "heavy traffic in coastal waters" to "heavy traffic in shallow or deep water"; and in the evening as a return to "shipping lane" traffic. A plot of AN at 50 Hz with respect to local time is shown in Figure 3.5. This illustrates the temporal variation due to distant shipping.

The individual shipping contribution to the noise field can be further subdivided into the noise generated by the ACANIA and by passing merchant traffic in the sea lanes. The number of ships that were observed to pass close to the measurement stations varied on a day to day basis. For example, in the December experiments, only one ship other than the ACANIA was sighted. On February 28, four ships passed the sonobuoy within a 3-4 hour period. This may in

TABLE IV

Standard Deviation Differences for Local and Distant Shipping for 1/3 Octave and Narrow Band Analysis

	NB		1/3	
	50 Hz	1700 Hz	50 Hz	1700 Hz
LOCAL SHIPPING	3-4 dB	2-3 dB	3-4 dB	2-4 dB
DISTANT SHIPPING	1.5-2 dB	0.5-1 dB	1.3-2 dB	0.5-1 dB

TABLE VIII

Hourly Readings of Wind Measurements using the ACANIA Anemometer and Hand-Held Anemometer

	HAND-HELD ANEMOMETER		ACANIA ANEMOMETER	
	LOCAL TIME	WIND SPEED (m/s)	LOCAL TIME	WIND SPEED (m/s)
	0958	6.4	0958	4.4
	1100	5.4	1058	4.8
FEB 26	1302	8.7	1204	5.9
	1400	9.4	1302	7.1
	1458	3.0	1400	4.1
			1500	3.6
	1303	4.0	1205	2.7
	1401	5.1	1303	1.9
FEB 28	1501	4.5	1401	3.1
	1601	5.0	1501	3.6
			1601	3.1

extracted from the Ross/Wilson AN curves (Siquig and Osborne, 1981) (Figure 3.10). The measured values were extracted from the 2 min AN records when nearby shipping was not a factor. As expected, increasing wind speed resulted in increasing AN levels. Good agreement is realized between the measured values and predicted values. The 1/3 octave band AN levels at 1000 Hz and 1700 Hz also show similar agreement. Figure 3.11 shows the ambient noise at 1700 Hz over the course of a day's measurements. Included is the 1/3 octave band processing of the data over the same time period. The fluctuations due to nearby ships (points 1 and 2) are visible but the AN is fairly constant otherwise. The wind speed was 6 m/s until 1300 and then increased to 9 m/s until 1500. These wind speeds correspond to Wenz estimates of 57 and 61 dB at 1700 Hz, respectively.

The close agreement between the predicted and measured values gives credence to predicting wind speed from AN measurements. This will also be possible with 1/3 octave band spectrum levels. The major limitation of this technique is the problem of contamination by individual ships. A noise level contaminated by such a source can lead to a gross over-estimate of the surface wind speed. As stated earlier, a ship outside 16 km will not contribute much to the wind-dependent spectrum. Hence, provisions must be made to either sample the noise frequently enough to preclude the possibility of individual ship intrusions without being recognized or else average the noise field so that a single sample will not greatly alter the mean value.

D. VARIABILITY

For each recorded cycle of AN a mean and standard deviation were computed for the selected frequencies. Each record length varied from approximately 15 min to 60 min.

Some of these records contained individual ship contributions while others included only distant shipping. Table X shows the average variability for the shipping and wind-dependent frequencies. When individual ships were present, a higher variability is seen for shipping-dependent frequencies, and for low wind speeds (5 m/s) a noticeably higher standard deviation (2-3 dB) is realized at 1700 Hz. The average hourly variability at 1700 Hz for higher wind speeds does not change appreciably for nearby shipping. The variability realized when distant shipping was the major contributor is about 2 dB less. The results agree favorably with Bannister et al.(1979). Figure 3.12 shows their results for shipping and a nominal 5 m/s wind speed. Also included in Figure 3.12 are Perrone's (1969) results. Plotted with these two curves are the range of standard deviations observed for 50 Hz and 100 Hz when nearby ships influenced the noise field. An increase in the wind speed resulted in a decrease in the standard deviation at 1700 Hz. At a wind speed of 5 m/s most standard deviations were 1-1.5 dB while at a wind speed of 10 m/s they were 0.5-1 dB. Though Figure 3.12 is limited to 500 Hz, it is apparent that the standard deviation trend is the same.

Figure 3.13 is an illustration of the measured sound speed as a function of depth. Trace A is the sound speed profile shape which was relatively constant for most at-sea measurement periods. Trace B is the sound speed profile measured during the December 12th exercise. The high wind speeds of 20 m/s and greater accounted for the wind agitation of the sea surface and a deepening of the mixed layer. This created a nearly isovelocity condition to 80 m and a steeper thermocline than would normally be expected.

The low frequency cutoff (Urick, 1983) was computed to be 250 Hz for the 80 m mixed layer. For the other periods the mixed layer depth was 25 m. The low frequency cutoff

TABLE IX

Average Daily Wind Speed, Average Measured AN, and Wenz or Ross/Wilson Values of AN at 1000 Hz and 1700 Hz

		MEASURED				PREDICTED	
	AVG W/S	NB 1000	NB 1700	1/3 1000	1/3 1700	WENZ 1000	WENZ 1700
DEC 11	11	67	63	66	63	66.5	64
DEC 12	19	73	70	72	69	71	68
FEB 26	6(am)	62	58	62	58.5	60	57
	9(pm)	63	60	63.5	60	64	61
FEB 28	5	59	55	60	55	59	56

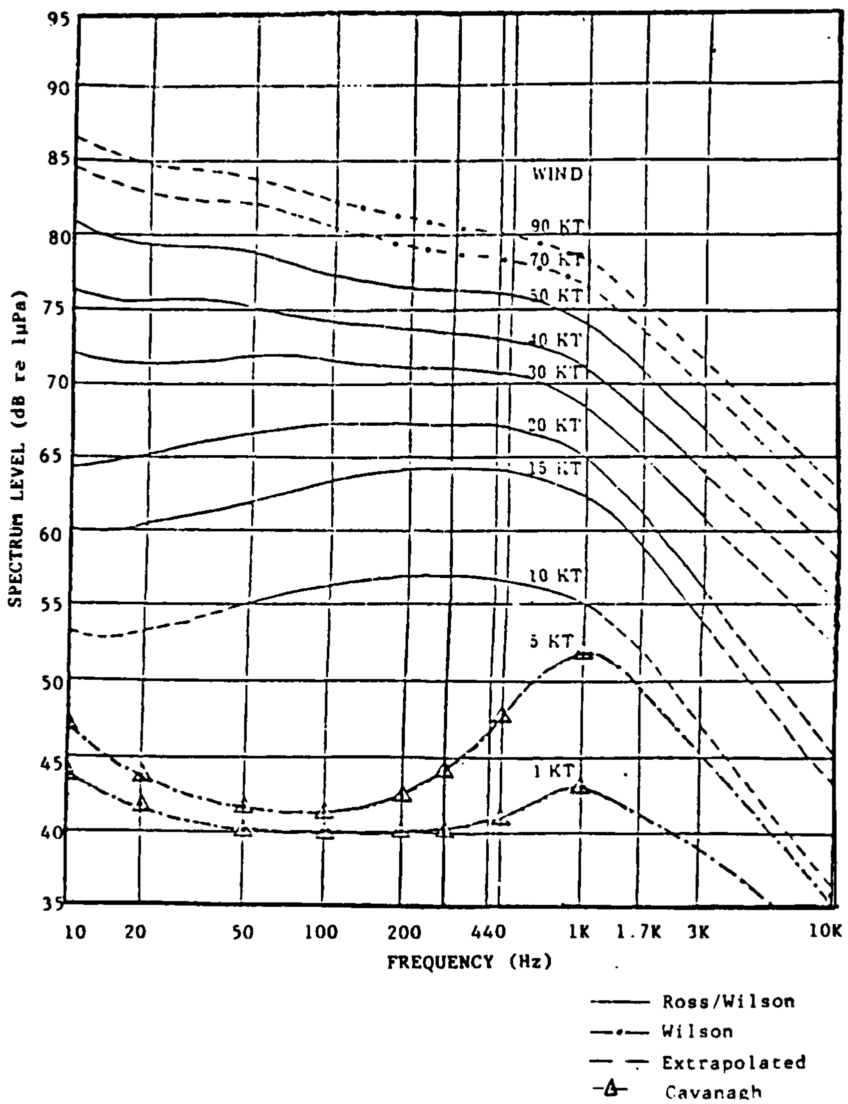


Figure 3.10 The AN spectrum in response to wind forcing as developed by Ross and Wilson (Siquig and Osborne, 1981).

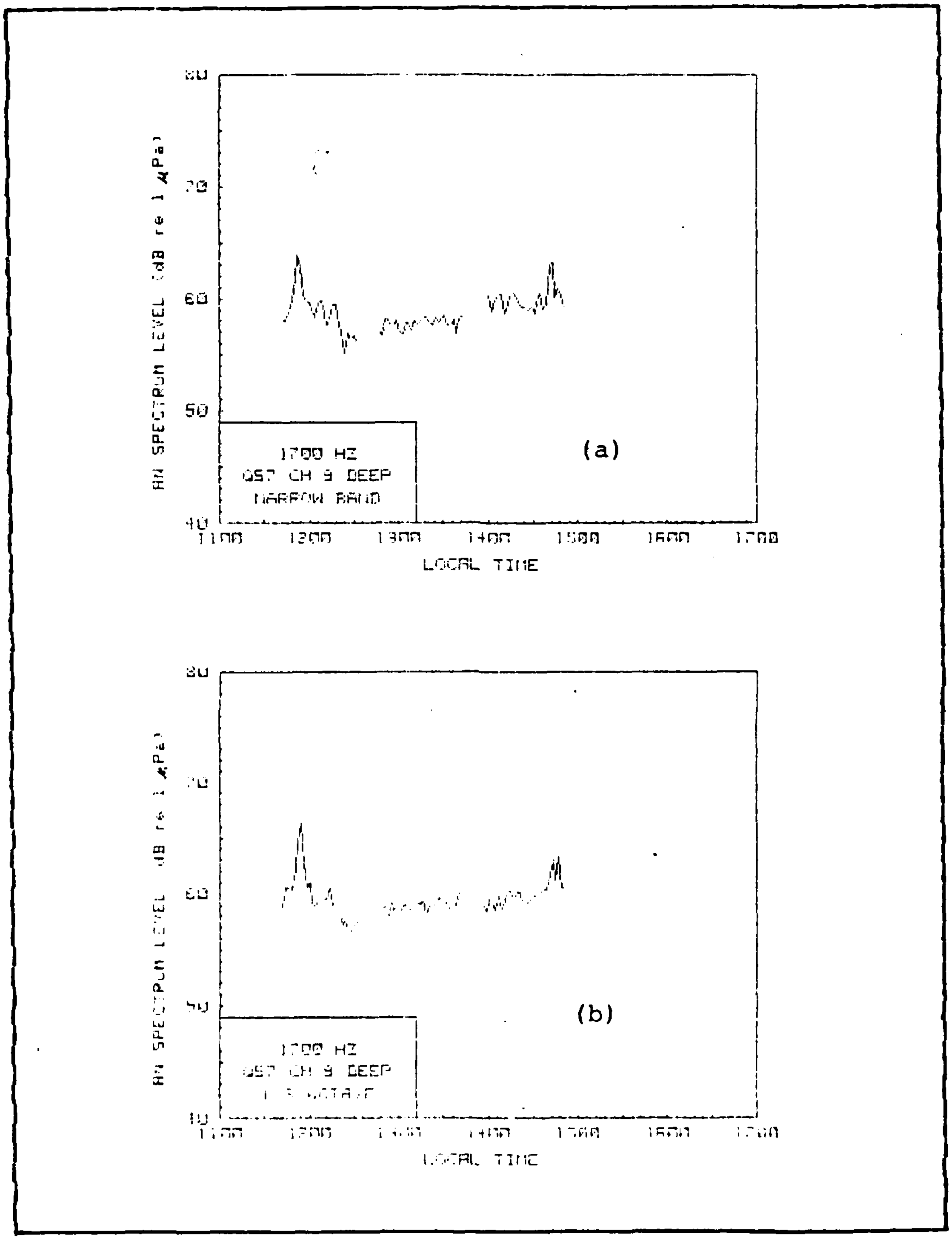


Figure 3.11 AN at 1700 Hz is plotted with respect to local time for (a) narrow band and (b) 1/3 octave band processing at Station 1.

TABLE X

Average Hourly Variability for Shipping and Wind-Dependent Frequencies

	SHIPPING		WIND (1700 Hz)		
	50 Hz	100 Hz	5 m/s	10 m/s	20 m/s
NEARBY	4-5	3-4	2-3	0.5-1	0.4-1
DISTANT	1.5-2.5	1.5-3	0.5-1	0.5-1	0.4-1

for this depth is 1400 Hz. Frequencies less than the cutoff frequency would leak out of the mixed layer while these greater than cutoff would be channeled. This effect was seen to hold true for all periods except December 12th. The 1700 Hz AN values are similar when measured by either the deep or shallow buoy. For frequencies less than 1700 Hz an average noise level measured at the deep sonobuoy is about 3 dB greater. Several explanations are possible for this strange occurrence. During tape playback, periods of self noise at the hydrophones were noticed due to the severe wave action. The self noise was more prominent on the deep hydrophone than the shallow one. This effect concurs with the results obtained by Lee (1982). The effect of the self noise was to increase the noise level for frequencies less than 1 kHz. Another possible explanation is that the shallow SSQ-41B had a 20 dB attenuation feature installed. The purpose of the attenuation feature is to attenuate high sea state noise (NAVAIRSYSCOM, 1983). It is possible that the amplitude of the AN was not appropriately corrected for by a 20 dB correction applied across the measured spectrum. Finally, these sonobuoys were designed to sustain sea state 5 conditions. The sea state on this day was 6 or greater. The sonobuoy design features which isolate the hydrophones from the wave action are not capable of doing so under these extreme conditions. The result is noise induced by motion of the cable or the hydrophone itself.

Due to the limited data obtained at Station 2 or 3, little can be said of the effects of the sloping bottom on measured ambient noise. From Figure 2.1 it can be seen that Station 2 is located in the deepest water, while Station 3 has fairly constant depth. Results show that the major influence is on the shipping portion of the frequency spectrum. Ambient noise levels measured at Station 3 when compared to Station 1 show 3-4 dB higher values at 50 and

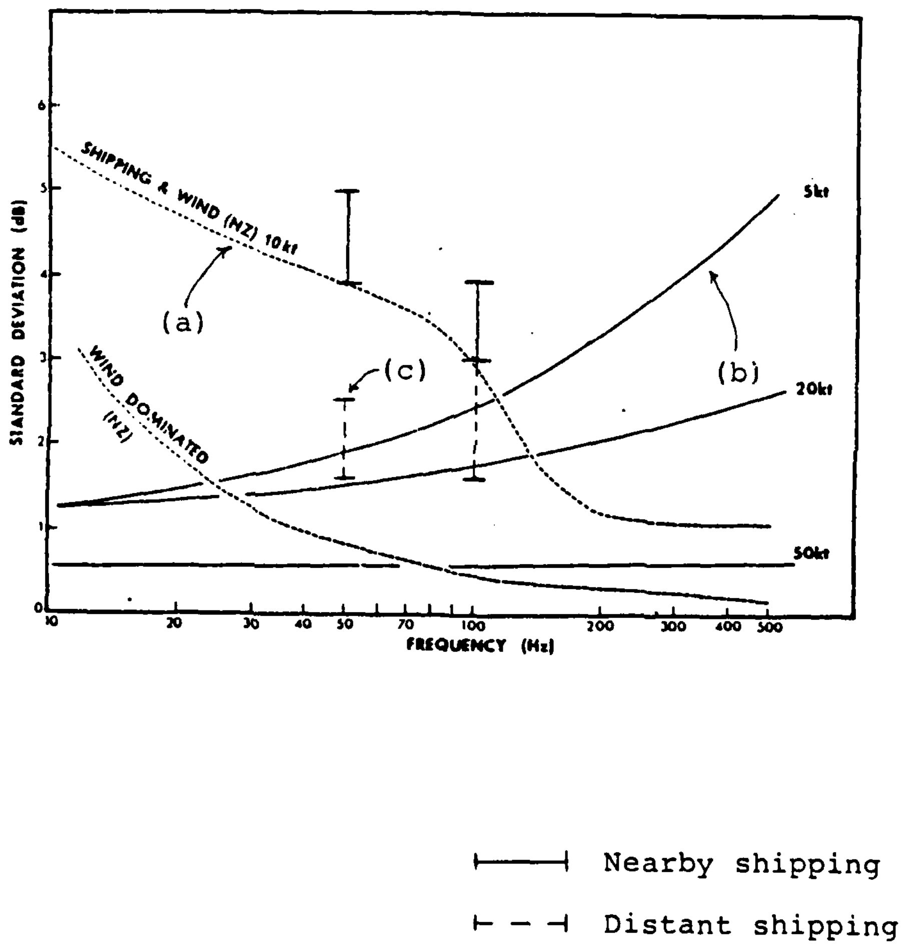


Figure 3.12   Comparison of AN variability:
(a) shipping and 5 m/s wind (b) Perrone wind data
(c) measured variability (from Bannister et al.,1979).

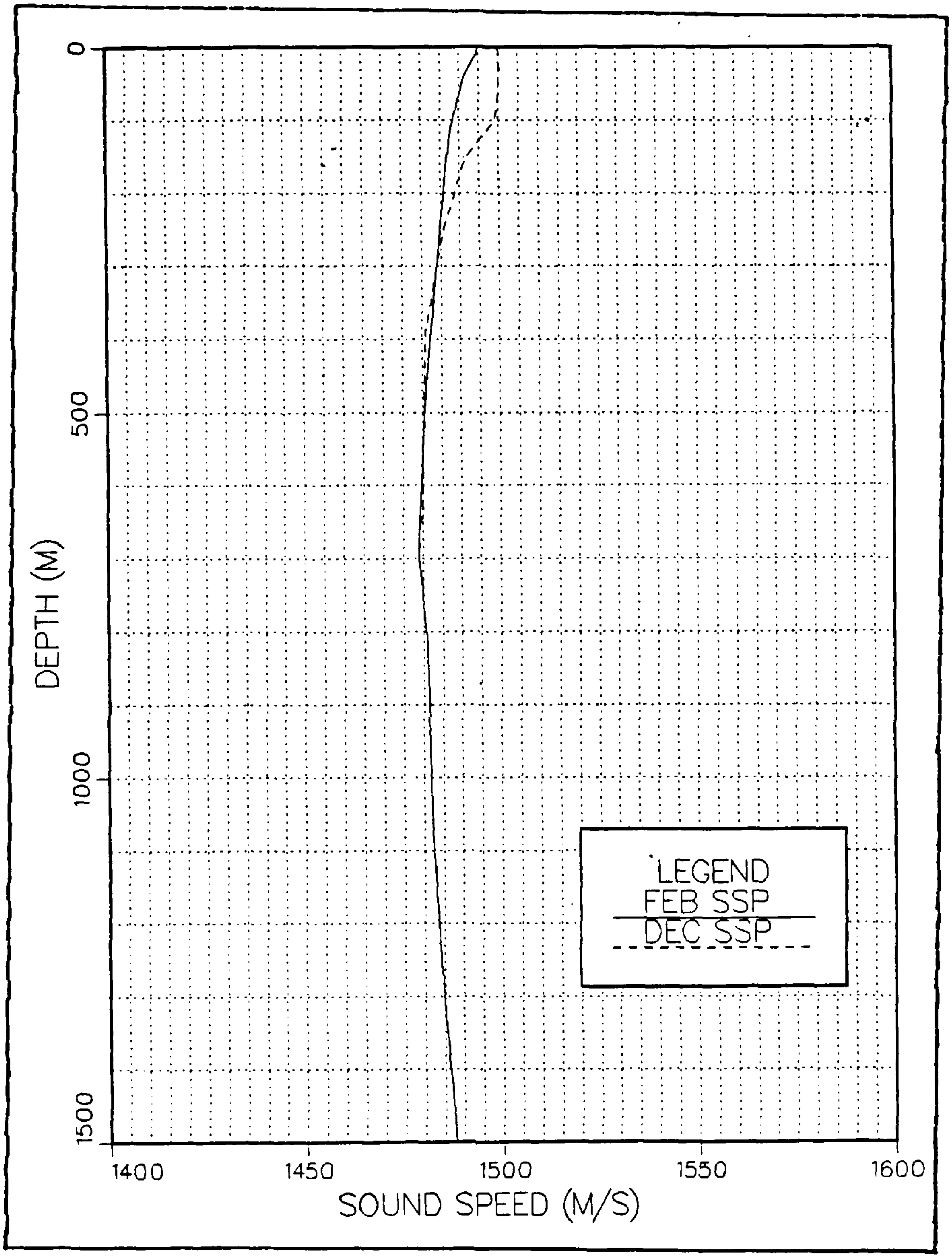


Figure 3.12 The normal sound speed profile is compared to one where high winds created a deep layer and steep thermocline.

100 Hz. This indicates that shipping noise is greater in this region. The individual ship contribution is more pronounced due to the closer proximity to the shipping lanes. The distant shipping contribution is also greater. A plausible hypothesis is a coastal enhancement (Ross, 1976) effect. Bathymetric charts show the water depth off San Francisco is shallower and extends further to the west than off Monterey. The propagation may be along the continental slope in a south-easterly direction and a loss of 3-4 dB may be due to reflections off the slope. This direction would be in accordance with that predicted by DANES. Buoys that are located on the slope (Station 1) suffer a 3-4 dB loss of shipping noise while those in more open water (Station 3) do not.

The wind-dependent noise is higher for Station 1 than Station 3. The wind frequencies of 1000 and 1700 Hz are 1-2 dB greater for the Station 1 sonobuoys indicating that shallower water yields higher AN due to wind.

IV. CONCLUSIONS

This study addressed the nature of ambient noise off the Monterey, CA coast in preparation for the eventual testing of the NADS buoy. The design of the NADS buoy dictated the analysis approach.

A comparison of narrow band and 1/3 octave band processing of AN up to 2.5 kHz shows that either method works equally well for determining the AN spectrum levels. Spectrum levels derived from a 1/3 octave band analysis can be used interchangeably with narrow band spectrum levels in the sonar equation within a 2 dB margin of error. Individual shipping will generally cause higher 1/3 octave band spectrum levels at higher frequencies due to the larger bandwidths and spectral nature of the shipping components.

The ASNI measured AN levels are comparable to 1/3 octave band spectrum levels. Usually 1/3 octave spectrum levels at 50 Hz are 1-2 dB higher than ASNI due to the smaller bandwidth (11 Hz vice 25 Hz). Frequencies above 50 Hz show close agreement between the two measurement methods. When local shipping is a factor, the comparison between ASNI and 1/3 octave band levels is more complex and is dependent on the source spectrum levels of the ship.

For the locations studied, the local and distant shipping contributions to AN can vary greatly. During the course of a day, the individual-ship influence may range from non-existent to several ships affecting the noise field. When this does occur there will be an increase in the AN through 2500 Hz. The individual-ship influence at 1700 Hz will cease to be important at ranges greater than about 16 km. For these winter observations, while a ship is in the area, the shallow hydrophone measured higher noise

levels above the cut-off frequency. For these exercises, a nominal mixed layer of 25 m was measured resulting in a cutoff frequency of 1400 Hz. The deeper hydrophone recorded higher noise levels for frequencies below this value due to leakage from the surface duct, horizontal directionality of distant shipping noise, etc. (Arase and Arase, 1967).

The distant merchant shipping will also vary on a day to day basis. This effect might be related to the amount of port activity in the San Francisco Bay area and the density of the shipping.

In agreement with Bannister et al. (1979), the variability of AN decreased with increasing frequency. High winds provided smaller standard deviations of the wind generated AN, while low wind speeds resulted in greater standard deviations. Nearby shipping tended to increase the standard deviations for shipping-dependent frequencies and only affected the wind-dependent frequencies when the wind speed was less than about 5 m/s.

Finally, surface wind speed can be estimated using measured AN values with a 1/3 octave band filter centered at 1600 Hz. The AN measurement at this frequency can then be used to enter empirically derived data which relate wind speed to AN level and predict the surface wind speed. Individual ship intrusions that go unnoticed will result in estimates that can be grossly in error. For this reason it is important to establish a sampling rate and averaging scheme for the NADS buoy that will permit the recognition of individual-ship influence on the noise field. It may be possible to establish this fact based upon the standard deviation at 1600 Hz. If a 1.5-2 dB standard deviation were seen for sampled values at this frequency, individual ship contamination can be assumed.

V. RECOMMENDATIONS

The equipment set-up as described in Chapter II is appropriate for the AN measurement and NADS buoy testing. Particularly important is the calibration of the tape recorder and sonobuoy receivers. Without careful preparation and documentation, processing of the noise data can become a troublesome chore based solely upon conjecture and hypothesis. The calibration of measuring equipment should be accomplished each day of the at-sea exercises.

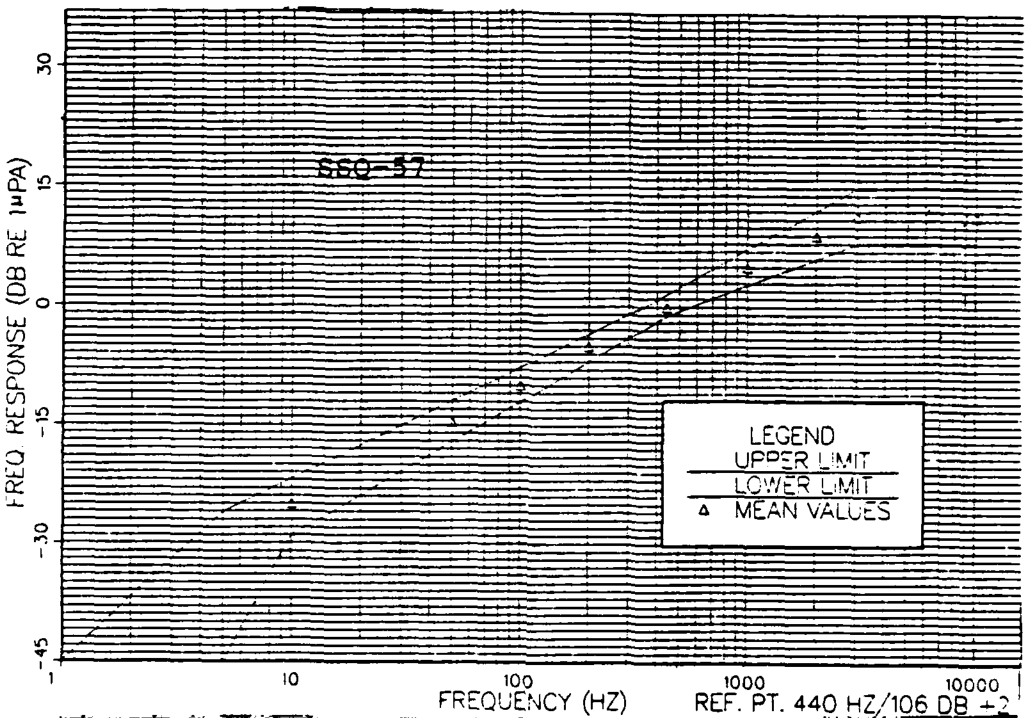
The NADS buoy should be deployed preferably at Station 1 or Station 2 along with a deep and a shallow SSQ-57 sonobuoy. This area would optimize reception of communications and the signals from the sonobuoys while keeping it somewhat more distant from shipping lanes. Consideration should be given to a weekend at-sea test due to the expected reduced port activity. A check with the harbor master in San Francisco may be helpful in determining the shipping traffic density. The two sonobuoys should be recorded continuously on the best receivers and tracks available as determined by the calibration performed prior to the exercise. Periodically the AN should be measured in the MASTF van using the ASNI and compared to the test-set indications of AN provided by the NADS buoy. The readings from the ASNI should be made slowly to allow for the internal integration time. At each selected center frequency a record should be kept of the highest, lowest and mean AN levels observed over a finite time interval (about 30 sec). This will provide a range of values to expect should the noise level be fluctuating considerably. A more in-depth analysis of the AN will have to be made in the laboratory, using an analysis procedure as suggested earlier

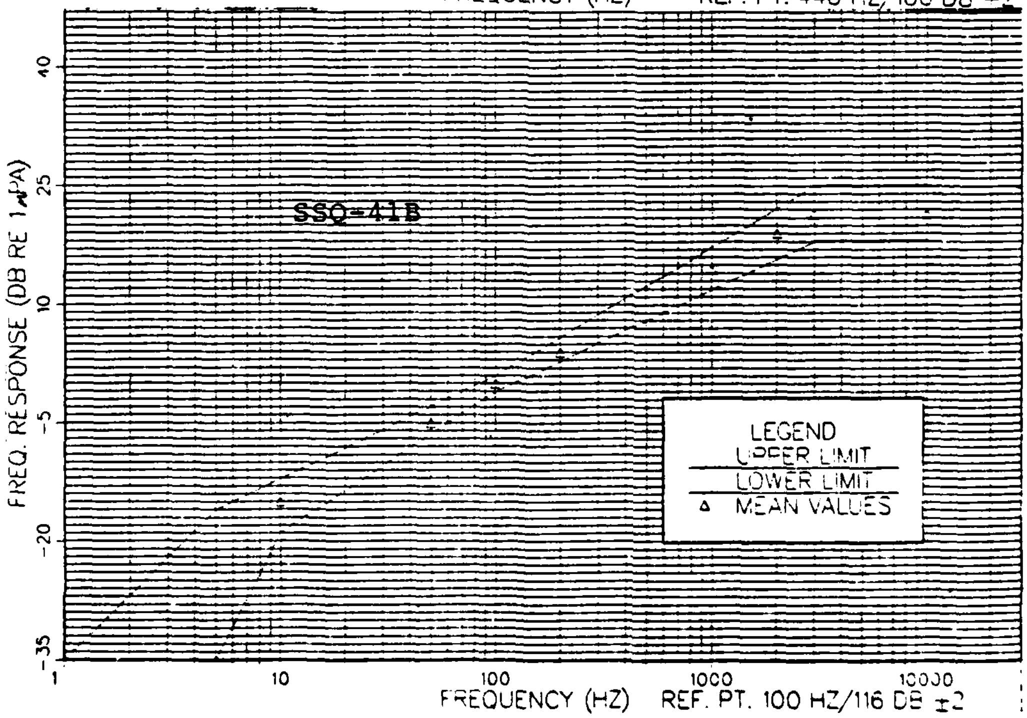
in this report. A comparison will then be possible between the shallow and the deep hydrophones of the NADS buoy and the SSQ-57 sonobuoys.

Finally, in order to document the processes involved in generating the noise field, an XBT and XSV should be deployed at the same location. Wind speed should be measured on a continual basis (this can be compared to NADS buoy measured wind) and a shipping plot maintained. To prevent the ACANIA from contaminating the noise field with spectral components it should remain at least 5 km away from the measurement site.

APPENDIX A

SONOBUOY SPECIFICATION CURVES





APPENDIX B

COMPUTER PROGRAM

```
1000  ! ............................................................
1010  !              Program Name : Sonobouy
1020  ! ............................................................
1030  ! ............................................................
1040  !                                     MAIN PROGRAM
1050    GOSUB Set date time
1060    GOSUB Initial
1070    GOSUB Recall data
1080    IF Source$="MEMOREX" THEN GOTO 1110
1090    GOSUB Setup spec ana
1100    GOSUB Collect data
1110    GOSUB Print data
1111    DISP "CONTINUE WHEN READY "
1112    PAUSE
1120    GOSUB Store data
1121    GOSUB Table
1130    GOSUB Terminate
1140 ! ------------- ---------------end-of-main-program-------------- -----
1150 !
1160 ! ............................................................
1170 ! ............................................................
1180 Initial:!
1190 ! ............................................................
1200    OPTION BASE 1
1210    INTEGER I,N
1220    PRINTER IS 1
1230    Rs=21.5
1240    Bs=90.1
1250    Bu=9.7
1260    Sq50=14.5
1270    Sq100=10
1280    Sq200=5
1290    Sq140=0
1300    Sq1002=-5
1310    Sq1720=-8
1315    DIM Array(21,7),Comment$[75]
1320    BEEP 900,.1
1330    INPUT "ENTER TABLE NAME",Name$
1335    INPUT "IS IT LIVE OR IS IT MEMOREX ?",Source$
1336    IF Source$="MEMOREX" THEN RETURN
1340    BEEP 900,.1
1350    INPUT "DATA START TIME",T
1360    BEEP 900,.1
1370    INPUT "ENTER CORRECTION FACTOR ",Cf
1380    BEEP 900,.1
1400    RETURN
1410 ! ---- - ------- ---- - -end-of-sub-routine ------------- ---- -
1420 !
1430 ! ............................................................
1440 Setup spec ana:!
1450 ! ............................................................
1470    DISP "SETTING UP HP 3561A FOR MEASUREMENTS"
1480    OUTPUT 711;"RST"
1481    OUTPUT 711;"SNGL"               !Single trace
1490    OUTPUT 711;"TCOM     "          !1/3 OCT BAND PROCESSING
1491    OUTPUT 711;"OCST 10KHZ"         !10 KHZ STOP BAND
1510    OUTPUT 711;"MAG"                !MAGNITUDE DISPLAY
1520    OUTPUT 711;"HANN"               !Hanning window
1540    OUTPUT 711;"AIEX"               !EXP Average
1550    OUTPUT 711;"NAVG10"             !WEIGHTED AVG OF 10 RECORDS
1555    OUTPUT 711;"OVRJ ON"            !OVERLOAD REJECT ON
1557    OUTPUT 711;"ARG"                !SINGLE AUTO RANGE
1560    TRIGGER 711
```

```
1600  ! ************************************************************
1610 Collect_data:!
1620  ! ************************************************************
1630    ON KEY 9 LABEL "INTERRUPT",15 GOTO 1970
1640    FOR J=2 TO 60 STEP 2
1650         N=J/2
1660         DISP "MEASURING SPECTRUM ON HP 3561A","  ","Time is ";T+J
1670         BEEP 1000,1
1680         Array(N,1)=J+T
1690         WAIT 120
1700         DISP "FILLING ARRAY WITH DATA"
1710         OUTPUT 711;"MMKP50HZ"
1720         OUTPUT 711;"RDMK"
1730         ENTER 711;X,Array(N,2),S,0
1740         Array(N,2)=Rs+Bs+Sq50-10.6+Cf+Array(N,2)
1750         OUTPUT 711;"MMKP100HZ"
1760         OUTPUT 711;"RDMK"
1770         ENTER 711;X,Array(N,3),S,0
1780         Array(N,3)=Rs+Bs+Sq100-13.6+Cf+Array(N,3)
1790         OUTPUT 711;"MMKP200HZ"
1800         OUTPUT 711;"RDMK"
1810         ENTER 711;X,Array(N,4),S,0
1820         Array(N,4)=Rs+Bs+Sq200-16.7+Cf+Array(N,4)
1830         OUTPUT 711;"MMKP440HZ"
1840         OUTPUT 711;"RDMK"
1850         ENTER 711;X,Array(N,5),S,0
1860         Array(N,5)=Rs+Bs+Sq440-19.7+Cf+Array(N,5)
1870         OUTPUT 711;"MMKP1000HZ"
1880         OUTPUT 711;"RDMK"
1890         ENTER 711;X,Array(N,6),S,0
1900         Array(N,6)=Rs+Bs+Sq1000-23.6+Cf+Array(N,6)
1910         OUTPUT 711;"MMKP1700HZ"
1920         OUTPUT 711;"RDMK"
1930         ENTER 711;X,Array(N,7),S,0
1940         Array(N,7)=Rs+Bs+Sq1700-25.7+Cf+Array(N,7)
1960    NEXT J
1970    RETURN
1980 ! -------------------------end-of-sub-routine----------------------
1990 !
2000 ! ************************************************************
2010 Print_data:!
2020 ! ************************************************************
2030    PRINTER IS 1
2040    PRINT USING "@"
2050    PRINT TAB(30);"AMBIENT NOISE ";Name$
2060    PRINT
2070    PRINT TAB(35);DATE$(TIMEDATE)
2080    PRINT
2090    PRINT "    ","Time","50 hz","100 hz","200 hz","440 hz","1000 hz","17
"

2100    PRINT
2110    FOR N=1 TO (J/2-1)
2120         PRINT "    ",Array(N,1),Array(N,2),Array(N,3),Array(N,4),Array(
Array(N,6),Array(N,7)
2130    NEXT N
2131    PRINT
2132    PRINT TAB(30);Comment$
2133    PRINTER IS 701
2140    RETURN
2150  ! -------------------------end-of-sub-routine----------------------
```

```
2200    IF TIMEDATE>=2.11E+11 THEN RETURN       ! Checks to see if default va
2210    DIM Today$[11],Clock$[5]                !   is set meaning our clock
2220    PRINTER IS 1                            !   updating.
2230    PRINT "Enter the date and time, SEPARATED by a COMMA,"
2240    PRINT "in the EXACT format shown below:"
2250    PRINT
2260    PRINT "      4 DEC 1984,9:54      "
2270    PRINT
2280    PRINT "Don't use leading zeroes EXCEPT for MINUTES !"
2290    ON ERROR GOTO 2300
2300    BEEP 1000,.2
2310    INPUT "Date  MONTH  Year (4 digits), Hour:Minutes ",Today$,Clock$
2320    SET TIMEDATE DATE(Today$)+TIME(Clock$)
2330    DISP TIME$(TIMEDATE),DATE$(TIMEDATE)
2340    BEEP 1000,.1
2350    WAIT 1
2360    Timedate=TIMEDATE                        ! Needed for READ statement
2370    OFF ERROR
2380    RETURN
2390    ! -------------------------end-of-sub-routine---------------------
2400    !
2410    ! ***************************************************************
2420 Store_data:!              STORES DATA ON FLOPPY DISC
2430    ! ***************************************************************
2431    IF Source$="MEMOREX" THEN RETURN
2440    PRINTER IS 1
2450    PRINT USING "///"
2460    PRINT "    You are invited to make any comments about "
2470    PRINT "this run to be stored with the data.  If you DO "
2480    PRINT "want to comment, type it in now  (keep it less"
2490    PRINT "than 2 screen lengths)."
2500    PRINT "When you're finished, press the ENTER key."
2510    PRINT
2520    PRINT "    If you've got nothing to add, just press ENTER."
2530    INPUT "Comments? ",Comment$
2540    DISP "STORING DATA"
2550    Array(31,1)=TIMEDATE                   ! Stores date/time of measurements
2551    Array(31,2)=J
2560    CREATE BDAT Name$,300,8                ! Creates a data file
2570    ASSIGN @Path1 TO Name$
2580    OUTPUT @Path1;Array(*),Comment$     ! Sends data to floppy disc
2581    ASSIGN @Path1 TO *
2590    DISP "DATA STORED UNDER FILENAME ";Name$
2600    RETURN
2610    ! -------------------------end-of-sub-routine---------------------
2620    !
2630    ! ***************************************************************
2640 Recall_data:  !
2650    ! ***************************************************************
2660    IF Source$="LIVE" THEN RETURN
2680    ASSIGN @Path1 TO Name$
2690    ENTER @Path1;Array(*)
2700    ENTER @Path1;Comment$
2710    ASSIGN @Path1 TO *
2711    J=Array(31,2)
2712    Timedate=Array(30,1)
2720    RETURN
2730    ! -------------------------end-of-sub-routine---------------------
```

APPENDIX C

SAMPLE TABLE OF AMBIENT NOISE MEASUREMENTS

DATE: 11 DEC 1984

BUOYTYPE: 057 CHANNEL 22 DEPTH: DEEP

METHOD OF ANALYSIS: 1/3 OCTAVE

Time	50 hz	100 hz	200 hz	440 hz	1000 hz	1700 hz
1247	83.655	75.235	69.885	68.08	66.315	63.87
1249	81.40	77.795	69.01	69.335	67.405	63.235
1251	83.07	75.935	69.365	68.455	66.55	63.415
1253	82.015	73.785	68.535	69.60	66.59	64.505
1255	81.99	74.915	68.07	68.47	67.215	64.67
1257	82.03	71.725	67.605	67.715	67.09	64.29
1259	80.915	71.08	69.91	67.975	66.61	63.145
1301	79.31	72.455	68.665	69.305	67.37	64.65
1303	78.905	71.035	69.675	68.475	67.745	64.65
1449	88.485	78.375	71.91	69.73	68.225	65.155
1451	91.39	79.11	72.22	70.32	69.44	64.95
1453	91.165	77.035	71.47	69.575	67.19	64.63
1455	90.29	76.075	71.42	69.95	68.02	64.925
1457	91.44	76.405	71.71	69.75	68.62	65.1
1459	93.12	79.05	72.93	69.99	68.525	64.94
1501	91.135	80	71.945	70.295	69.015	65.465
1503	97.145	78.21	72.91	70.305	68.985	65.105
1505	94.355	77.875	72.57	70.195	67.405	65.5
1507	93.405	77.61	73.43	70.415	68.91	65.615
1509	96.065	78.25	73.44	70.615	69.725	65.8
1511	97.165	80.41	73.04	71.23	68.565	65.735
1513	99.275	81.765	72.06	71.71	68.72	66.09
1515	99.0	82.375	72.95	70.73	67.24	66.105
1517	98.985	82.065	73.525	71.30	68.24	65.455
1519	98.20	80.21	73.27	70.39	69.02	65.19
1521	97.685	78.78	73.015	71.32	68.985	65.775
1523	95.825	78.35	73.165	70.22	68.14	65.34
1525	94.03	77.34	73.24	70.32	68.325	64.23
1527	93.67	78.11	73.48	69.95	67.19	65.71

APPENDIX D

A SAMPLE OF MEAN AND STANDARD DEVIATION RESULTS

DATE: 26 FEB 1985

BUOYTYPE: 057 CHANNEL 9 DEPTH: DEEP

METHOD OF ANALYSIS: NARROW BAND

Time		50 hz	100 hz	200 hz	440 hz	1000 hz	1700 hz
1142 1200	MEAN=	91.34	87.66	78.93	79.63	67.42	60.35
	SD=	1.55	2.01	2.31	6.71	2.29	1.37
1202 1234	MEAN=	90.58	79.74	73.22	77.31	62.72	57.77
	SD=	1.76	2.94	2.99	7.32	2.[illegible]	1.49
1247 1343	MEAN=	88.76	74.63	68.84	68.22	62.26	57.[illegible]
	SD=	1.42	2.24	1.52	3.99	.7	.49
1357 1451	MEAN=	91.47	77.04	70.41	69.52	64.15	59.51
	SD=	2.26	1.68	1.59	3.08	1.19	[illegible]

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